Spatial and Statistical Prediction of Urban Malaria in Yaoundé: A Social and Environmental Modelling Approach for Health Promotion

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Nothing can be more important to a State than its public health; the State’s paramount concern should be the health of its people.

Franklin D. Roosevelt
(In a report to the new Legislature, 1931)

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To my beloved wife and children who supported my long absence during the realisation of this study

To my beloved mother and sisters for taking care of me during these moment.

To my family in law in Cameroon

To my brother

To my deceased father for inspiring me

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My childhood in Cameroon, and memories of people suffering from various illnesses, particularly malaria, were the initial factors that pushed me to be involved in geomedical studies. My desire to bring my modest contribution to a better public health status on the earth in general, and in Cameroon particularly, is equivalent to my scientific interest in medical geography and malaria studies. Sharing knowledge with people has always been a part of my wishes, which I have tried to express in a useful scientific way in this study.

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Abstract

Most of the existing predictive malaria risks models use very broad spatial scales. They are usually built for continental or national outlines. These models do not account for the complexity of socio-economic variables intervening in the malaria transmission process. Most of them are driven by weather data. However, it is difficult to make antimalarial interventions at a continental or national level and to act on climate variables alone. Consequently, the suitability of these models for real malaria prevention strategies is not high. Moreover, the existing informational-based prevention strategies are not suitable, since they are usually limited to the occasional usage of large public mass media to transfer bits of information.

This study proposes new paths in malaria modelling and prevention. It is dedicated to the building of a thematically extended model integrating both environmental and social variables. The proposed prevention strategy is based on an educational philosophy integrating the actual malaria modelling results. The study starts with the implementation of a methodology dedicated to data creation and data analysis. The protocol of data creation is based on urban malaria paradigm. It encompasses the epidemiological, environmental, and social components of malaria risk. The epidemiological component is elaborated through retrospective, self-reported, malaria febrile and clinical episodes of individuals at the household level. In addition to climate data, key ecological variables are created from remote sensing sources with a very high spatial resolution. New social indexes and coefficients measuring economic status, crowding conditions and prevention capacity of the population are created. A morphospatial structure of Yaoundé, which assumes the presence of distinct population aggregates, representing similar socio-economic profiles, is established using an object-oriented classification of QuickBird images. A spatial based index of urbanity (IU), quantitatively marking the difference between “urban” and “rural” patterns, is also built. A knowledge-base expressing the social, ecological and malarial significance of both population aggregates and index of urbanity is established and used in a Fuzzy Logic simulation approach to predict urban malaria in Yaoundé.

The yearly malaria prevalence based on individuals in households in Yaoundé is 9% while the malaria prevalence based on households as an entity is 27%. Malaria prevalence is higher during the small rainy season. It is much more marked in peri-urban areas during this season, while people in central areas are more exposed during the big rainy season. A statistical multinomial model identified socio-economic and socio-ecologic variables, notably those related to the physical condition of houses, as being highly associated with frequent episodes of malaria in households. Variables related to prevention capacity perform very well in predicting the absence of malaria in households. Among the ecological variables, only elevation and the distance to urban agriculture (UA) areas are associated with malaria. The statistically (from multinomial models), overall-predicted household prevalence of malaria is lower than the observed one. The morphospatial structure of the city shows a clear distinction between very dense, centralized and “urbanized” population aggregates (PA) and very isolated, mostly peri-urban, “rural” population aggregates. The morphological model suggests that the intensity and sustainability of the malaria transmission are both dependant on demographical gradients. The less urbanized population aggregates, although being in proximity of urban agriculture areas, are demographically not suitable for a sustainable malaria transmission. The most urbanized population aggregates are too dense and too far from urban agriculture areas. This does not favour local malaria transmission. This rigid ecological pattern is somewhat biased by the identified social patterns. The densest population aggregates mostly host very poor people. This allows a part of this population to be at a high

risk of malaria through localized urban farming activities. The other parts of dense population aggregates are located in centrally situated planned zones. They have better socio-economic and socio-ecologic conditions which significantly reduces their vulnerability to malaria. Population aggregates with suitable demographic conditions (not too dense or too isolated), in addition to a higher environmental and social vulnerability, are the most exposed. Although the Fuzzy Logic simulation procedure produces a predicted prevalence which is lower than that of the overall multinomial model, it also identifies these intermediate population aggregates as being the most exposed.

Results of interviews show that, in general, the knowledge and perception of people of basic key factors associated with malaria transmission is bad. Moreover, this knowledge follows a social stratification with the richest people having the best background. An association between knowledge and prevention behaviour is also established. In order to use the model for malaria prevention, three educational game-based tools have been created. The tools are designed for different target audiences with regard to required support and cognitive capacities. A follow-up method based on a pre- and post-test, before- and after-, play sessions is used to measure the information transfer capacity of each game to players who had various social profiles. Until now, official antimalarial campaigns in Cameroon used other media such as posters, television, and paper journals. Games had been not used at all before. From the point of view of players, the proposed games are highly attractive. Among them, the computer-based one, mixing visual and audio cognitive aspects in the information transfer, shows a good information transfer capacity. Furthermore, the degree of progress in the acquisition of malaria relevant information is highly dependent on the frequency of play.

Zusammenfassung (Abstract in German language)

Die meisten der bisher entwickelten voraussagenden Malaria-Risiko-Modelle benutzen eine grobe räumlichen Auflösung. Sie wurden zumeist für Kontinente oder Staaten entwickelt. Diese Modelle berücksichtigen nicht die verschiedenen komplexen sozioökonomischen Faktoren, die die Malariaübertragung beeinflussen. Zumeist werden lediglich Wetterdaten herangezogen. Es ist allerdings sehr schwierig, Malariapräventionen auf einer kontinentalen oder nationalen Ebene durchzuführen, und ausschließlich basierend auf klimatischen Variablen zu handeln. Aus diesem Grunde eignen sich diese Modelle nur sehr eingeschränkt für wirkliche Malariapräventionsmaßnahmen. Darüber hinaus sind auch die vorhandenen informationsbasierten Präventionsstrategien nicht geeignet, da diese für gewöhnlich auf eine gelegentliche Verwendung der Massenmedien für den bruchstückhaften Informationstransfer beschränkt sind.

Die vorliegende Studie empfiehlt neue Wege in der Modellierung und Prävention von Malaria. Sie ist der Erarbeitung eines thematisch erweiterten Modells gewidmet, welches sowohl soziale als auch ökologische Variablen integriert. Die vorgeschlagenen Präventionsstrategien basieren dabei auf einer pädagogischen Philosophie, die die aktuellen Ergebnisse der Malariamodellierung integriert.

Am Anfang der Studie steht die Entwicklung der Datenerfassung und –analyse, wobei die Erfassung auf einem städtischen Malariaparadigma beruht. Dieses beinhaltet die epidemiologischen, ökologischen und sozialen Komponenten des Malariarisikos. Die epidemiologische Komponente wurde mittels rückblickender selbstberichteter Daten zu fieberhaften und klinischen Malariaepisoden auf der Haushaltsebene erarbeitet. Neben klimatischen Daten wurden weitere elementare ökologische Variablen aus Fernerkundungsdaten generiert, die eine sehr hohe räumliche Auflösung besitzen. Es wurden neue soziale Indices und Koeffizienten erarbeitet, die den Lebensstandard, den Grad an Überbevölkerung und die Malariapräventionskapazität der Bevölkerung messen. Eine morpho-räumliche Struktur, die ähnliche sozioökonomische Profile auf der Basis einer objektorientierten Klassifikation von QuickBird Daten repräsentiert, und das Vorhandensein ausgeprägter Bevölkerungsaggregate voraussetzt, wurde für die Stadt Yaoundé festgestellt. Ein räumlich basierter Index der Urbanität (UI), der den Unterschied zwischen „städtischen“ und „ländlichen“ Strukturen quantitativ ausweist, wurde ebenfalls entwickelt. Eine Wissensbasis, die die soziale, ökologische und die Malaria betreffende Bedeutung der beiden Bevölkerungsaggregate sowie die des Index der Urbanität beschreibt wurde erstellt und in einem Fuzzy-Simulations-Ansatz zur städtischen Malariavorhersage für Yaoundé benutzt.

Die jährliche Malariaverbreitung basierend auf Individuen in Haushalten liegt in Yaoundé bei 9%, während die Malariaverbreitung basierend auf Haushalten als Einheit bei 27% liegt. Die Malariaverbreitung ist während der kurzen Regenzeit höher. Sie ist deutlich ausgeprägter in peri-urbanen Gebieten während dieser Jahreszeit, wohingegen die Bevölkerung der städtischen Gebiete vor allem während der langen Regenzeit von Malariaerkrankungen betroffen ist. Ein statistisches Multinominalmodel identifizierte sozioökonomische und soziökologische Variablen, vor allem jene, die in Beziehung zum baulichen Zustand von Häusern stehen, als stark mit häufig auftretenden Malariafällen in Haushalten zusammenhängend. Variablen, die auf die Präventionskapazität bezogen sind, ergeben sehr gute Ergebnisse bei der Vorhersage von Nichtauftreten von Malaria in Haushalten. Unter den ökologischen Variablen besteht nur für die Geländehöhe und den Abstand zu innerstädtischen Landwirtschaftsarealen (UA) eine Beziehung mit dem Auftreten von Malaria. Das statistisch (aus multinominalen Modellen) allgemein prognostizierte Malariaauftreten in Haushalten ist

geringer als das Beobachtete. Die morpho-räumliche Struktur innerhalb der Stadt zeigt eine klare Unterteilung zwischen sehr dichten, zentralen und „städtischen“ Bevölkerungsaggregaten und sehr isolierten, zumeist peri-urbanen und „ländlichen“ Bevölkerungsaggregaten. Das morphologische Modell zeigt, dass die Intensität und Nachhaltigkeit der Malariaübertragung von demographischen Gradienten abhängt. Die weniger urbanisierten Bevölkerungsaggregate, auch wenn sie in direkter Nachbarschaft zu städtischen Agrargebieten liegen, sind demographisch nicht für eine nachhaltige Malariaübertragung geeignet. Gleiches gilt für die städtischsten Bevölkerungsaggregate, die zu dicht und zu weit von den urbanen Landwirtschaftsräumen entfernt sind. Dieses starre ökologische Raster wird etwas durch die identifizierten sozialen Strukturen verzerrt. Die dichtesten Bevölkerungsaggregate beinhalten zumeist sehr arme Menschen, wodurch ein Teil dieser Bevölkerung von einem großen Malariarisiko durch örtlichen urbanen Ackerbau betroffen ist. Der andere Teil der dichten Bevölkerungsaggregate wohnt in zentrumsnahen geplanten Gebieten. Sie haben bessere sozioökonomische und sozioökologische Bedingungen, welche die Vulnerabilität gegenüber Malaria signifikant reduzieren. Bevölkerungsaggregate die die entsprechenden demographischen Gegebenheiten (nicht zu dicht oder zu isoliert), zusätzlich zu einer höheren ökologischen und sozialen Vulnerabilität aufweisen sind am meisten gefährdet. Dabei generierte die Fuzzy-Logic-Simulation eine geringere Malariaauftrittsprognose als das allgemeine Multinominalmodel; es identifizierte ebenfalls die mittleren Bevölkerungsaggregate als die der am meisten der Malariagefährung ausgesetzten.

Interviewergebnisse zeigten gewöhnlich, dass Wissen und Wahrnehmung von grundlegenden Schlüsselfaktoren der Malariaübertragung bei der Bevölkerung schlecht sind. Dieses Wissen ist sozial stratifiziert, die reichsten Menschen haben den besten Hintergrund. Es wurde ebenfalls eine Verbindung zwischen Wissen und Präventionsverhalten festgestellt. Um das Model zur Malariaprävention zu nutzen, wurden drei lernspielbasierte Hilfsmittel entwickelt, die verschiedene Zielgruppen im Hinblick auf die erforderliche Unterstützung und kognitiven Kapazitäten ansprechen sollten. Mittels einer Follow-Up Methode, die auf einem Pre- und Posttest vor und nach dem Spielen basiert, wurde die Informationstransferkapazität jedes Spiels für seine Spieler, die unterschiedliche soziale Profile auswiesen, gemessen. Bis heute nutzen offizielle Antimalariakampagnen in Kamerun andere Medien, wie Poster, Fernsehsendungen und Zeitschriften. Spiele wurden bisher noch überhaupt nicht für diese Art der Aufklärung genutzt, obwohl aus der Sicht der Spieler die vorgeschlagenen Spiele hoch attraktiv waren. Eines der Spiele, welches Computer-basiert ist und visuelle und kognitive Aspekte beim Informationstransfer mischt, zeigt eine sehr gute Informationstransfer-Kapazität. Außerdem ist der Grad des Fortschrittes im Erwerb malariarelevanter Information stark von der Häufigkeit des Spielens abhängig.

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List of abbreviations

ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
AIDS: Acquired Immune Deficiency Syndrome
AMSU: Advanced Microwave Sounding Unit
CCD: Cold Cloud Duration
DEM: Digital Elevation model
DMSP: Defence Meteorological Satellite Program
EC: Economic Capacity
EIG: Coefficient integrating regular cleaning of the surrounding environment of a household, usage of insecticides and presence of protective grids (nets) on windows.
EIR: Entomological Inoculation Rate
EOS: Earth Observing System
GeoMedIS: Geomedical Information System
GIS: Geographical Information System
GiZ: Getis ord Index
GPI: Global Polynomial Interpolation
GTS: Global Telecommunication System
HDFM: Household Distance to Feature Method
HIS: Health Information System
IDW: Inverse Distance Weighing
IRAD: Institut de Recherche Agricole pour le Developpement
IU: Index of Urbanity
LPI: Local Polynomial Interpolation
LST: Land Surface Temperature
LSTM: Liverpool School of Tropical Medicine
LULC: Land Use and Land Cover
MAETUR: Mission d'Aménagement et d'Équipement des Terrains Urbains et Ruraux
MARA: Mapping Malaria Risk in Africa
MINUH: Ministère de l'Urbanisme et de l'Habitat
Mlogit: Multinomial logistic regression
MRR: Malaria Relative risk
NDVI: Normalized differenced vegetation Index
NOAA: National Oceanic and Atmospheric Administration
PA: Population Aggregates
RBF: Radial Basis Function
Rc: Room crowding
RFE: Rainfall estimate
SIC: Société Immobilière du Cameroun
SSA: Sub-Saharan african
SSM/I: Special Sensor Microwave/Imager
UA: urban agriculture
USGS: United States Geological Survey
VI: Vegetation Indexes
WMO: World Meteorological Organization

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1 Introduction

Much like the image of Sisyphus, who was condemned to permanently roll a stone on the summit of a mountain (CAMUS, 1942), it appears that African countries are condemned to solve permanent public health crises. Malaria and AIDS are the primary public health problems that are symptomatic to this situation. All the programs and resources allocated to reduce the burden of these illnesses seem to have had no positive effect.

These public health crises reflect the general economic and socio-political crises in most African countries. This is a vicious circle, where the bad economic and socio-political crises influence the poor conditions of public health; in return, the poor public health conditions are an obstacle to harmonious economic development. The situation is such that there is a lack of resources for both public health and socio-economic needs. Understanding the spatial aspects of the major public health concern at various scales is required in order to better control their territorial aspects. It should lead to optimal utilization of the available resources.

The scientific interest in malaria is such that multiple programs involving different scientific fields have been created. In fact, the complexity of malaria needs a multidisciplinary approach. Whether it is biology, geography, sociology, mathematics or epidemiology, each of the scientific fields associated with malaria research is important. This approach would lead to a better understanding and prediction of malaria. However, the application of fundamental scientific findings should be a priority for a real impact on prevention strategies. In this sense, educational sciences could be of inestimable importance.

1.1 Malaria-a dramatic and persistent public health concern

In 2006, there were an estimated 247 million malaria cases among 3. 3 billion people at risk in the world. Of these cases, 86% were in Africa. Among the estimated 881,000 malaria deaths, 91% took place in Africa (WHO, 2008). Malaria is the primary cause of mortality and morbidity in Africa. The severe consequences of malaria are borne most heavily by the poorest citizens (20%) (BARAT et al., 2004). The widespread distribution of malaria is related to the complex nature of its life cycle. The factors favouring malaria outbreaks go beyond the basic biological elements and include ecological as well as socio-economic factors (WILSON, 2001). Malaria perpetuates the vicious cycle of ill-health and poverty because it has a negative impact on socio-economic development (SACHS & MALANEY, 2002).

Earlier in the 1930s, urban malaria studies were conducted in the port cities of Mombassa, Dar es Salaam and Tanga (WISEMAN et al., 1939; MACKAY, 1935; WILSON, 1936). This was an exception to the norm for such studies: previous malaria studies in Africa had been widely focused on rural areas, largely because the continent's population was mostly rural. In 1900, only 10% of Africans were living in an urban area. But these proportions have increased rapidly, so that today almost the half of the population in Sub-Saharan Africa (SSA) (45% in 1999) lives in urban and peri-urban areas. These proportions are expected to grow dramatically (see fig. 1).

The beliefs of the authors of the first studies on urban malaria in 1930 (WISEMAN et al. 1939; MACKAY, 1935,; Wilson, 1936) were that the urban malaria problem would be resolved simply with the ongoing process of urbanization. This was in reference to the epidemiological transition history elsewhere in western societies. In western societies, almost all of the vector–borne diseases have been eradicated, simply by the process of modernisation, involving a safe environment and better hygiene. This observation does not account for the ecological difference that exists between safer tropical areas and temperate zones. The fact that it has not been solved has become a matter of concern. In fact, the process and characteristics of urbanization are not the same in SSA as it has been in the developed countries. These demographic trends, combined with the increasing crowding in SSA's cities are making urban malaria an emerging public health problem. This is illustrated by the fact that individuals who were previously never exposed to malaria in cities are now experiencing severe malaria episodes (BAUDON & SPIEGEL, 2001).

A cross disciplinary conference on urban malaria in Africa, was held in Pretoria in South Africa, on December 2-4, 2004. Sectors represented at the conference were water, agriculture, eco-health systems, epidemiology, entomology, community health, NGO's and social sciences. The malaria-Knowledge Programme's key partners were the System-wide Initiative on Malaria and Agriculture (SIMA), the International Water Management Institute (IWMI), the Environmental Health Project (EHP, USAID) and the International Development Research Centre (IDRC). The Technical Consultation on the Strategy for the Assessment and control of Urban Malaria of this conference stated that an increasing proportion of the African population live in urban areas where many individuals are at significant risk of malaria. Strategies used to control malaria in rural areas cannot be directly transferred to urban settings, since they are likely to result in a significant waste of resources. They also stated that there are important gaps in the knowledge of malaria in the urban context.

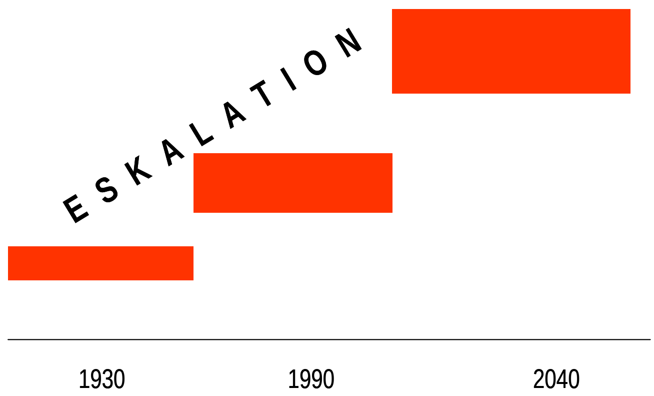

Figure 1: Probable escalation of urban malaria (NGOM & SIEGMUND, 2007[a])

1.1. Problem statement and research objectives

Does an integration of social and ecological variables at a very high spatial resolution provide a better understanding and forecast of the problem of urban malaria? The general objectives consist of the building of geostatistical and geospatial predictive models of malaria. These models will include multiple socio-economic and ecological variables. This fundamental scientific output will be interconnected with an educational concept aiming to facilitate the dissemination of key scientific malaria information to the public. This preventive orientation will be illustrated by the introduction of the fundamental scientific results into education-based tools. The ultimate objective will be the assessment of the proposed tools (see fig. 2).

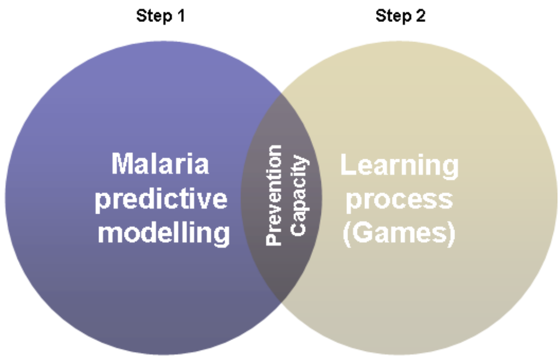

Figure 2: Two scientific entities to strengthen urban malaria prevention capacity

These general objectives are derived from specific hypotheses. The following specific hypotheses are the guidelines for the analyses developed and the results reported in this thesis:

1. The prediction of urban malaria depends on the integration of both ecological and social variables in malaria models.
2. A cost- and time-efficient simulation of spatial malaria risk in Yaoundé depends on the integration of key ecological and social variables into a knowledge-base associated with remote-sensing data.
3. A comprehensive set of key scientific information on malaria could be more efficiently transmitted to a large public through tools adapted to the local socio-cultural context.

The specific hypotheses listed above define the following specific objectives:

1. Build statistical and high spatially calibrated predictive models of urban malaria in Yaoundé using selected ecological and social variables.
2. Elaborate a level of malaria knowledge based on the social and ecological morphospatial structure of the city and simulate malaria risk from this knowledge-base.
3. Implement the modelling results in locally adapted educational tools and assess their capacity for transmitting information. .

1.2. Contribution of this thesis

The added value of this study is related to the spatial frame of the proposed models. It also proposes a comprehensive approach, integrating both ecological and social variables. This study contributes to the understanding of the complex of social and environmental variables that occur in complex milieus such as Sub-Saharan African (SSA) cities. The proposed knowledge-base helps to optimize the existing resources for malaria prevention. The automated-prediction orientation of this knowledge-base is an innovative attempt to predict urban malaria using concepts based on artificial intelligence. The broader spatial scales of the existing models, as well as the exclusion of social factors intervening in the malaria-transmission process, considerably reduce the preventive effectiveness of these models. This shortcoming is avoided within this study. The actual study offers a higher decision-making capacity.

It is the first time that scientific results concerning malaria, particularly urban malaria, are connected to an educational concept aiming to facilitate the diffusion of key malarial information. This set of filtered information is amenable to help develop a better understanding of malaria processes, and therefore to implement a sustainable prevention strategy. As such, the philosophy of the proposed educational tools is completely innovative in the SSA context. Unlike existing prevention media, the information integrated in the proposed tools is holistic.

1.3. Thesis organization

The remaining sections of this thesis are organized as follows: Chapter 2 discusses the background of urban malaria studies that focus specifically on the African context. It also proposes an urban malaria paradigm for designing a conceptual model of potential social and ecological variables relevant to the transmission of urban malaria. This chapter also gives a brief, social and ecological description of the city of Yaoundé, with a succinct epidemiological and entomological statement of its suitability to malaria transmission. Chapter 3 is dedicated to the description of the methodology. It describes in detail the data-gathering and production procedures. It explains how the malarial statistical models are created. It also describes the methodology used to map out a malarial knowledge-base. This chapter shows how this malaria knowledge-base was introduced into a malaria spatial-modelling approach using a Fuzzy Logic method. Chapter 4 presents the results of all the fundamental scientific analyses, while Chapter 5 shows how these results are merged with a pedagogical concept designed to successfully transfer malarial information for prevention purposes. This chapter assesses the information-transfer capacity of dedicated antimalarial tools. Chapter 6 discusses the results of this research, presents some ideas for future work, and concludes the thesis. The list of literature used in the thesis and appendixes are given at the very end.

2 State of the art

After introducing the malaria problem in a broader global public health context, and after defining the specific hypotheses and objectives of the actual study in the last chapter, the present chapter introduces a view of malaria studies in Africa. It focuses on the types of variables commonly associated with malaria. It defines an urban malaria paradigm differentiating it from rural malaria studies. It emphasizes the limits of the spatial outlines commonly used within malaria studies. This chapter also makes a snapshot analysis of the strategies commonly used to prevent malaria in Africa and in Cameroon. The chapter provides a succinct description of geographical, socio-economic as well as epidemiological and entomological features of the city of Yaoundé, as provided by various authors.

2.1 Geomalaria studies-one problem two dimensions

Using the United Nations 1996figures on urbanization, remotely sensed images and the MARA (Mapping Malaria Risk in Africa) database, Snow and colleagues (SNOW et al., 1999) estimated that 200 million people (24.6% of the total African population) currently live in urban settings where they are at risk from malaria. It can be said that the interest in urban malaria is recent, since urbanization itself is a recent phenomenon in SSA. Data presented in studies in a number of SSA cities (Brazzaville Congo, Dakar Senegal, Abidjan in Ivory Coast, Dar es Salaam Tanzania, Accra and Kumassi Ghana) clearly show that urban malaria is a significant public health problem in Africa. The adaptation of malaria vectors to urban ecosystems has been well documented for three decades, and local transmissions have been conclusively demonstrated in many African cities. (CHINERY, 1984; BARBAZAN, 1985; TRAPE et al., 1987; COENE, 1993; LOCHOUARN, & GAZIN,. 1993; PHILLIPS, 1993; ROBERT et al., 1993; MANGA et al., 1993; JULVEZ et al., 1997; THOMPSON, 1997; BARBAZAN et al., 1998; DOSSOU-YOVO et al., 1998; MEUNIER , 1999; EL SAYED,. 2000; BAUDON & SPIEGEL, 2001; NIMPAYE et al., 2001; ROBERT et al., 2003; SARAH et al., 2003; DE CASTRO et al., 2004; DONELLY et al., 2005; KEISER et al., 2005).

Many studies have focused on the relationship between land cover, land use, and the spatial dynamics of mosquitoes. Regardless of the importance of temperature and rainfall in the malaria cycle, their relationship to malaria outbreaks has been shown not to be strictly linear. Reiter (REITER, 2000), for example, wonders why malaria was so prevalent during some of the coldest centuries in Europe this past millennium. (SHANKS et al., 2000) in a study in Kenya detected no link between climate variables and malaria admissions. (LINDSAY et al., 2000) in Tanzania highlands found that after one El Niño event with 2.5 [times] more rainfall than normal, there was less malaria than before. These results suggest that other factors of environmental and socio-economical origin could be more important than climate.

Remote sensing and Geographical Information Systems (GIS) have been frequently used to forecast malaria epidemics (LOSLIER et al., 1995; HAY et al., 1996; HAY et al., 2000; CURRAN et al., 2000; BECK, 2000; WILSON, 2002; KIGBAFORI et al., 2008). They are very useful tools in public health and communicable diseases studies (SCHWEIKART & KISTEMANN, 2001). Most of the remotely sensed imagery used in malarial studies had a very broad spatial resolution. They were, in fact, limited in their potential for detecting malaria-related ecological and socio-ecological features. This evidence points out the problem of geographical scales of malaria models. It is most common for researchers to consider results coming from such spatially broader RS images. The plan including such a resolution is much more suitable to a global approach that includes crucial general information on the ecology of malaria. It could be much more suitable for rural malaria because ecological features apparently dominate this environment. The urban ecosystem is demographically and socially much more complex. Its spatial contiguity requires very high spatial resolution products (BREMAN et al., 2004).

2.2 The urban malaria paradigm

2.2.1 Malaria life cycle

There are over 120 species of the parasite genus of *Plasmodium* (BEALAND, 2006). However, only four of these infect humans to cause malaria. These four species of *Plasmodium* parasites are *Plasmodium falciparum*, *Plasmodium vivax*, *Plasmodium ovale* and *Plasmodium malariae*. *Plasmodium falciparum* can cause severe malaria and the other three species cannot. *P. falciparum* are responsible for the most life-threatening form of malaria and cause the majority of the deaths worldwide.

The life cycle of malaria is described in terms of development stages of the malaria parasite that takes place in different environments (see fig. 3). Only the female *Anopheles* carrying malaria causing parasite will feed on a human and injects the parasites in the form of sporozoites into the bloodstream (C) (1) (see fig. 3). This blood meal of the *Anophele* is necessary for the maturation of its eggs and the *Anopheles* produces eggs several times during her life. Thus, she will regularly need a host (vertebrate) for her blood meal.

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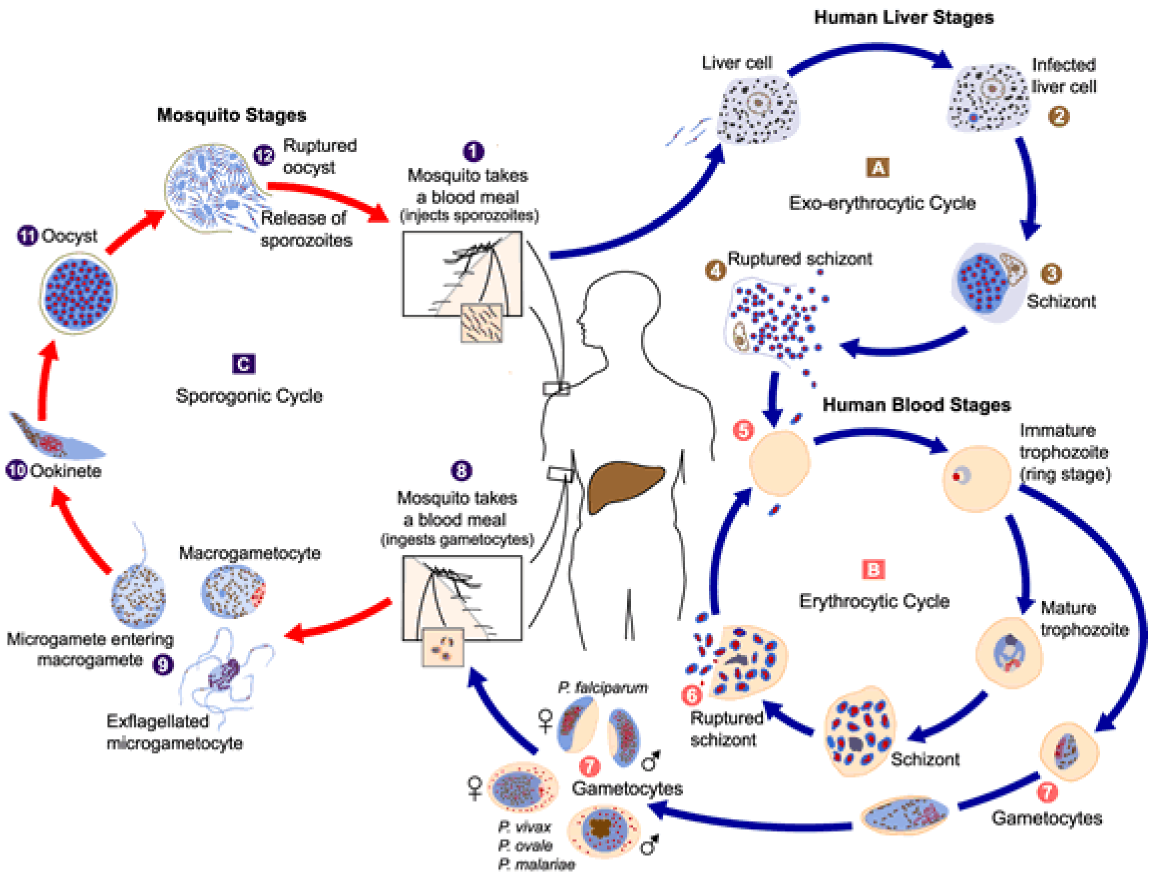


Figure 3: Life cycle of malaria parasite (After the Center for Disease Control (CDC), www.dpd.cdc.gov)

The biological cycle of the malaria parasite is divided into three. One takes place in the mosquito; it is the sporogonic cycle. The other two take place in the human host; they are the erythrocytic cycle and the exo-erythrocytic cycles (fig. 3 and 4). The gonotrophic cycle is concerned with the egg production, the laying cycle of the mosquito (fig. 4).The sporozoite travels with the blood to the liver and enters the liver cells (A) (2). In the liver, some of the sporozoites divide and become thousands of merozoites. The merozoites enter the blood after being released from the liver cell and are taken by the red blood cells (B) (5). In the red blood cells, some merozoites turn into ring-formed trophozoites (d) which split again to form schizonts (d). The schizonts burst the red blood cells (B) (5) at a certain moment, releasing the merozoite which in turn infects more red blood cells. Each burst of red blood cells is associated with violent rise of temperature and severe body chill as seen during the attacks in malaria. The trophozoites that were left over during the division will develop into a sexual form, the male and female gametocyte (B) (7). The gametocyte is the form that infects mosquito and reproduces itself. When the uninfected mosquito has sucked blood (C) (8) containing gametocytes, they pass into the salivary glands of the mosquito, where they develop into a new form, the sporozoites. The parasite matures inside the mosquito until it reaches the stage where it can again infect a human host when the mosquito takes her next blood meal, 10 to 14 or more days later.

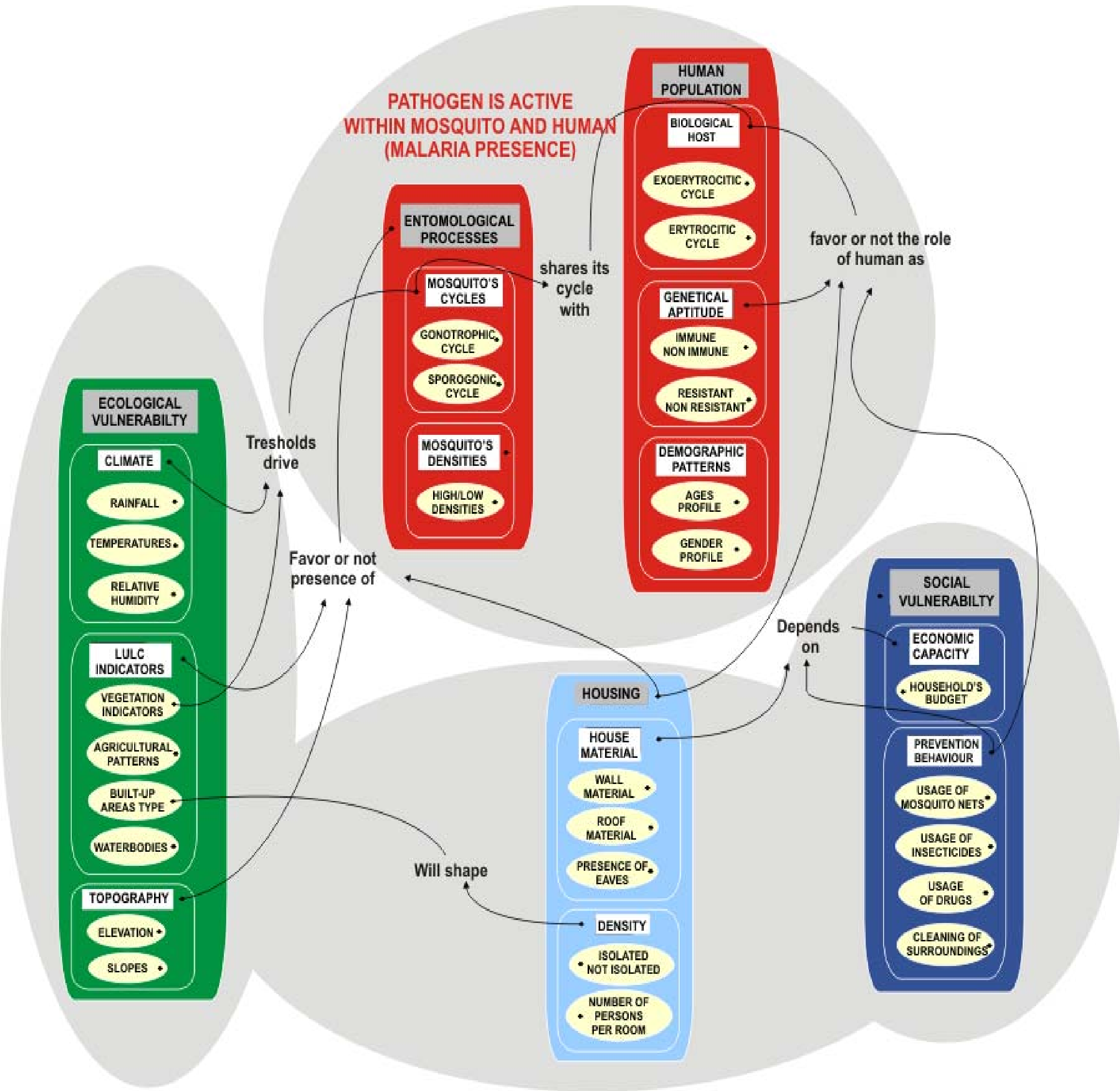


Figure 4: Urban malaria: a complex of ecological and social factors (NGOM & SIEGMUND 2009[a])

2.2.2 Urban malaria risks and associated factors

In SSA, the vulnerability of urban populations to vector-borne diseases is both ecological and social. The ecological vulnerability is associated with the entomological processes and includes climatic, topographical and biomass factors (vegetation, vegetation indexes) that determine the reproduction and development of the *Anopheles* mosquito and its pathogen agent (SMITH et al., 1999). Socio-ecological elements such as the quality of housing can favour the biological development of mosquitoes (KIRBY et al., 2008). Social vulnerability derives from a number of factors that allow the human population to become a host in the life cycle of the malaria parasite (see fig. 4).

Among the factors favouring entomological processes related to the malaria parasite life cycle, temperature has been identified as being closely linked to the duration of the sporogonic and gonotrophic cycles (HADDOW et al., 1943; JEPSON et al., 1947). There exist temperature thresholds that will impact on the duration of the mosquito's biological cycle (see fig. 5).

The optimum identified temperature for *P. falciparum* is between 25°C and 30°C. Below 18°C and beyond 40°C, conditions are not favourable for survival (DETINOVA, 1962; MARTENS, 1997). The existence of mosquito's eggs, larvae and pupae depends on the presence of breeding sites, typically stagnant water pools mainly filled by rainfall. Hydrological features such as water streams and other water bodies constitute good potential predictors. The productivity of these water bodies will also be dependent on their temperatures. According to the spatial variations of climate conditions worldwide, malaria will be absent, endemic or epidemic in various places. The African equatorial zone is providing favourable conditions for holo- and hyper-endemicity (see fig. 6).

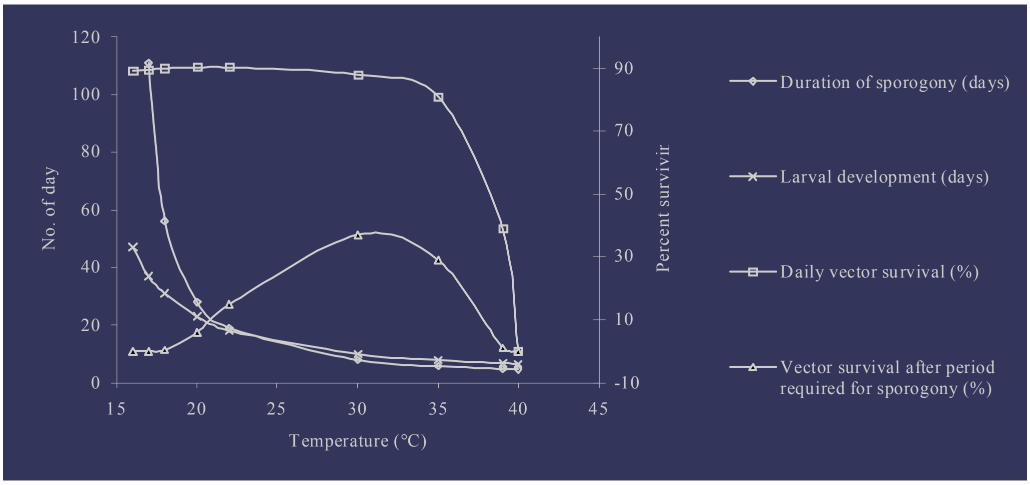


Figure 5: Temperature dependence of parasite and vector (After the International Research Institute for Climate and Society (IRI) http://iridl.ldeo.columbia.ed)

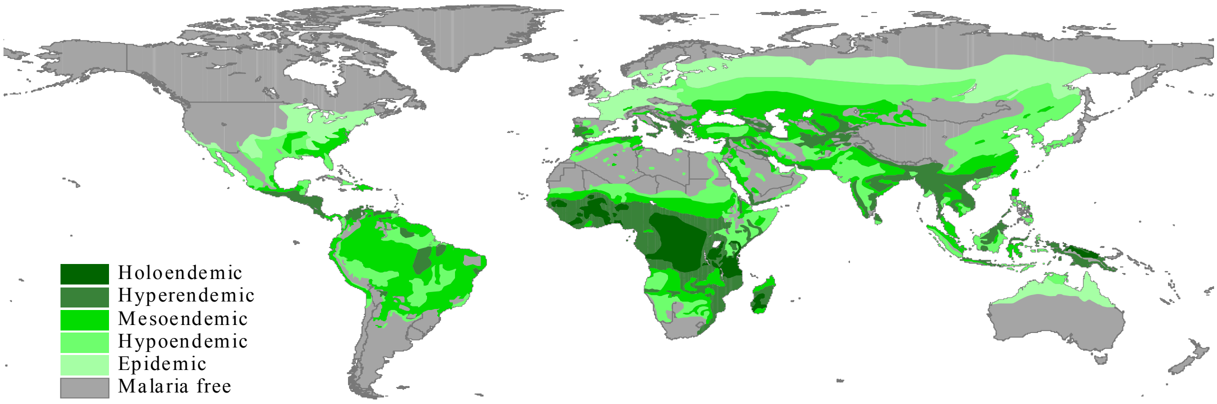


Figure 6: Geographical limits of malaria endemicity in relation to the 60˚F (15.6˚C) & 70˚F (21˚C) summer isotherms (After the International Research Institute for Climate and Society (IRI) http://iridl.ldeo.columbia.ed)

High slopes can be an obstacle to mosquito long distance flights as well as for the choice of flight directions. They can be a determining factor to the extension of malaria-transmission (MANGA et al., 1993). Vegetation and particularly vegetation indexes (VI) have been identified as being very good indicators of breeding sites presence because they indirectly express the humidity of an ecological *nidus* (HAY et al., 2000). In addition to water bodies and vegetation, features of land use and land cover (LULC), namely built-up areas, are very important factors in an urban context. What will also be of importance in the set of ecological variables influencing malaria-transmission is Urban Agriculture (UA). Despite the fact that UA patterns are somewhat the result of human activities, they bear extensive representations of natural ecological features like water bodies and vegetation. They are, by the way, a very special ecosystem. They are different to social factors by the fact that social variables are basically analysed at an individual level. Many studies have demonstrated the relationship between UA and malaria (GIMNIG et al., 2001; BETSI et al., 2003; BRIET et al., 2003; AFRANE et al, 2004; KOUDOU et al., 2005; KLIKENBERG et al., 2004; SATTLER et al., 2005: KLIKENBERG et al., 2008).

Two types of social factors can be considered. The first one refers to the socio-ecological factors that are at the margins of ecological and social factors. These variables are driven by the physical condition of housing (see fig. 4). It has been demonstrated that the type of material present in the walls and roofs of houses are correlated with the presence of mosquitoes. It also has been stressed that the presence of eaves favours a higher indoor biting rate (KIRBY et al., 2008). There is a positive correlation between households with high human population densities and mosquitoes' high densities (TAKKEN & KNOLS, 1999). A study conducted in Yaoundé and Edea (urban Cameroon) concluded that mosquito survival was not compatible with densely populated areas (MANGA et al., 1993). This suggests that the level of isolation of a household will be an important factor to the presence of mosquitoes.

The second type of social predictors is related to the socio-economic status (WILSON, 2001) and malaria prevention behavior of potential hosts (see fig. 4). It is argued that understanding the socio-cultural dimensions of the burden of malaria is vital for the development of interventions in order to access vulnerable groups (ALILO et al., 2004). Professional activity, level of education, use of mosquito nets, utilization of insecticides, use of preventive antimalarial drugs, regular cleaning of the house surroundings, use of drugs, and utilization of protective grids on the windows constitute a barrier to indoor biting. Pyrethroid treatment, for example Deltamethrin treated bed nets, has shown a significant reduction in the transmission of malaria in the Kou valley, Burkina Faso (ROBERT & CARNEVALE, 1991) as well as reduction in child and infant mortality in some malaria endemic African countries (SACHS & MALANEY, 2002). Use of pyrethroid-impregnated bed nets by all members of the community appears to be a major tool in preventing transmission of malaria (ROBERT & CARNEVALE, 1991).

2.3 Malaria prediction and prevention-what about the spatial scales and the social variables?

Epidemiological models have been developed to describe and predict various aspects of the life history of vector-borne diseases. Rogers was the first to incorporate critical components of a parasite's intricate life cycle into a mathematical model and used it to predict the incidence of malaria within human populations (ROGERS, 1988). Rogers and Packer (Rogers & Packer, 1993) also provided a good overview of vector-borne diseases, which includes a discussion of both epidemiological and geographic distribution models. Among the predictive spatial malaria models developed for Africa, the best known are the MARA models (Mapping Malaria Risk in Africa) (MARA/ARMA, 1998). These models use climate and additional ecological variables, such as elevation, to predict malaria. The Liverpool Malaria Model (Liverpool School of Tropical Medicine, University of Liverpool), by Thompson and colleagues, is a predictive statistical and spatial weather driven model, integrating complex meteorological data with malaria epidemiological data to reconstruct and predict the prevalence of malaria infection (THOMPSON et al., 2006).

Despite the fact that these models are of a crucial scientific relevance, their practical importance for field intervention is limited, when considering the rapidly changing socio-demographic trends in Africa. There are three main limitations: firstly, the low geographical resolution used by these continent-wide or large scale models; secondly, the absence of social factors as predictors; and thirdly, the inaccurate distribution pattern of the African population, which is growing rapidly in cities and therefore spatially concentrating into urban aggregates.

Agyepong and colleagues (AGYEPONG et al., 2004) suggested a pathway that helps create effective monitoring and evaluation systems in a framework for longitudinal, iterative, and evidence-based decision-making. According to Over and his colleagues, Health Information Systems (HIS) of the future will need much greater coherence in using malaria and fever incidence reduction (OVER et al., 2004)

2.4 Malaria prevention strategies-what directions and priorities?

Preventive measures can be divided into two major factors: personal control and vector control. No reliable vaccine against malaria has been available until now. As well, until now, the prevention of malaria had followed the same paths. Many efforts and funds are provided for therapy (drugs) and prevention through chemoprophylaxis drugs, bed nets and insecticides. The problem is that these strategies seem to be advantageous only for the "industry of malaria." Different programmes aimed at eradicating malaria in Africa brought questionable results. For example, the large-scale efforts at vector control through DDT campaigns deployed in Africa from the 1950s to the 1970s did not succeed in eradicating malaria, but favoured the development of mosquito resistances (CURTIS & LINES, 2000; CURTIS et al., 2000). Meanwhile, the ability of the *P. falciparum* parasite to mutate and adapt has led to widespread drug resistance. In addition, the lack of political will for clear, social, and economic mean-term and long-term planning, in the most affected countries, is not helping to sustainably reduce the malaria burden in those countries. At the end, it is always the poor citizens who are the most exposed to the transmission of malaria (SACHS & MALANEY, 2002).

Coping strategies are not integrating a comprehensive, sustainable and economically reasonable approach that considers the local resources. It is thus surprising that in a country like Cameroon where malaria is a very important public health concern, educational programs are not extensively developed and integrated into the formal educational system (HUGON, 1996). Funds are invested in posters advising people to use bed nets. This has been done for more than 30 years. There exists no measurement of the impact of such consciousness-raising methods. The mean and long term impacts of educational aspects on the reduction of malaria prevalence are not considered at all.

2.5 The city of Yaoundé and malaria-transmission

2.5.1 Urban and rural patterns in a growing city

Yaoundé, the capital of Cameroon, is located between 3° 52' 21'' N and 11° 31' 03'' E in central Africa. The administrative outline of Yaoundé encompasses a total of 140 km^2. It corresponds to the administrative division of the Mfoundi (see fig.7).

In this study, the urban area refers to an administrative spatial definition (which corresponds to the department of Mfoundi). It includes central and peri-urban zones. In the case of Yaoundé, peri-urban zones are geographically closer to rural zones than centrally situated zones. Peri-urban and rural areas also share ecological similarities. In fact, the city belongs to the global equatorial forest ecosystem. It is surrounded by the green forest. The development of the city has been made at the expense of this green forest. Relics of this green forest are still visible today (see fig. 8).The city has a mean elevation of 750 meters. The steeped landscape of Yaoundé is at the origin of its popular surname "the city of seven hills".

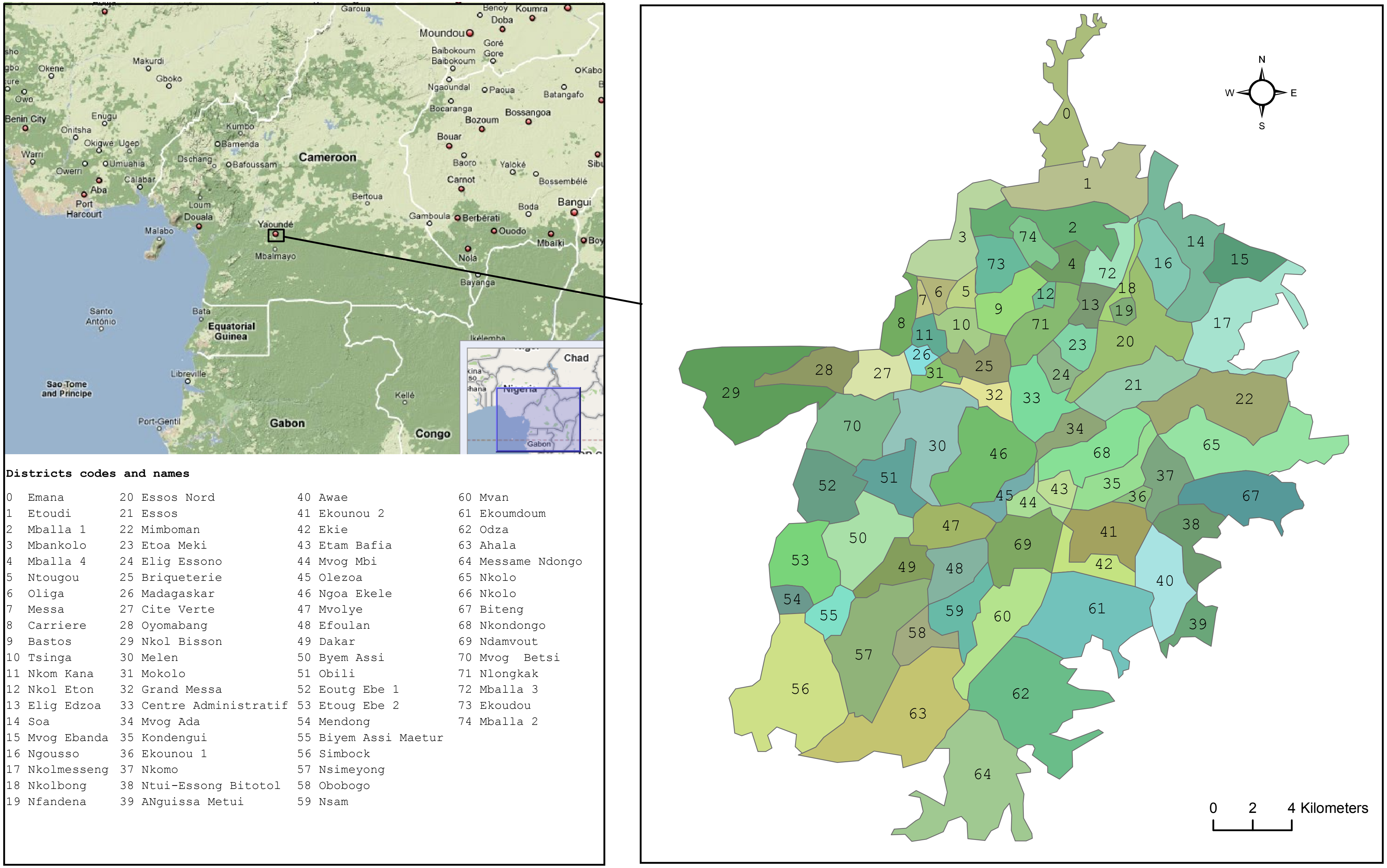


Figure 10: Location of yaoundé and its districts (Raw data sources: Communauté Urbaine de Yaoundé (CUY), 2000)

Figure 8: 3D overview of Yaoundé

The climatic regime is equatorial with a bimodal rainfall feature. Rainfall exceeds 1600 mm per year. Mean temperatures vary from 18°C to 28°C in the wet season and from 16°C to 32°C in the dry season. The mean temperature is between 17°C and 30°C yearly. The climate of Yaoundé is usually divided into four seasons: a big dry season that runs from the end of November to February, a small rainy season from March to June, a small dry season from June to August and a big rainy season from August to November (see fig. 9)

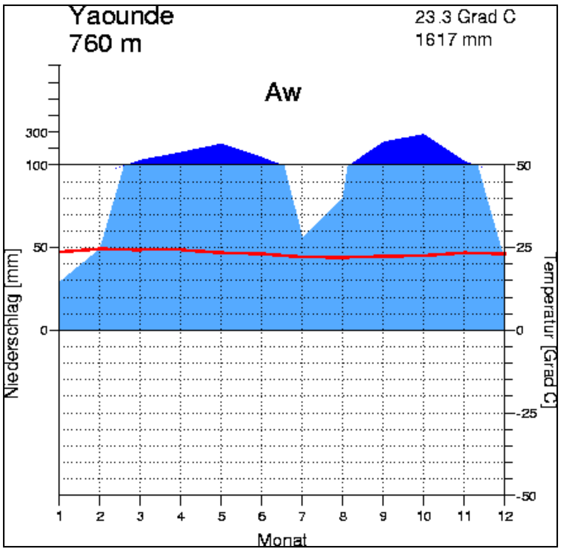


Figure 9: Climate diagram of Yaoundé (After www.klimadiagramm.de)

2.5.2 Demography and socio-economic role of Yaoundé

Yaoundé is growing rapidly; it expanded tenfold between 1957 and 1990 without any specific urban planning or architectural orientation (ENIMELI et al., 2005). According to the urban community of Yaoundé (COMMUNAUTÉ URBAINE DE YAOUNDÉ, 2000), the morphological structure of the city can be regrouped into spontaneous, intermediate and planned habitats (see fig.10).

Assako Assako estimates that an important part of the spontaneous habitat (see fig.11) corresponds to colonized valleys where many are classified as natural risk zones (ASSAKO ASSAKO, 1997). An important part of the inhabitants of spontaneous zones are legally installed. These non-planned zones were formed around the first nucleus of the city at the proximity of communications networks (roads) and services (administrative and domestic). They formed the most densely populated zones where accommodations such as sanitations services, water supply facilities are absent (PROUZET, 1996; MINISTÈRE DE L'URBANISME ET DE L'HABITAT, 1996). This spontaneous structure is less prevalent in peri-urban areas.

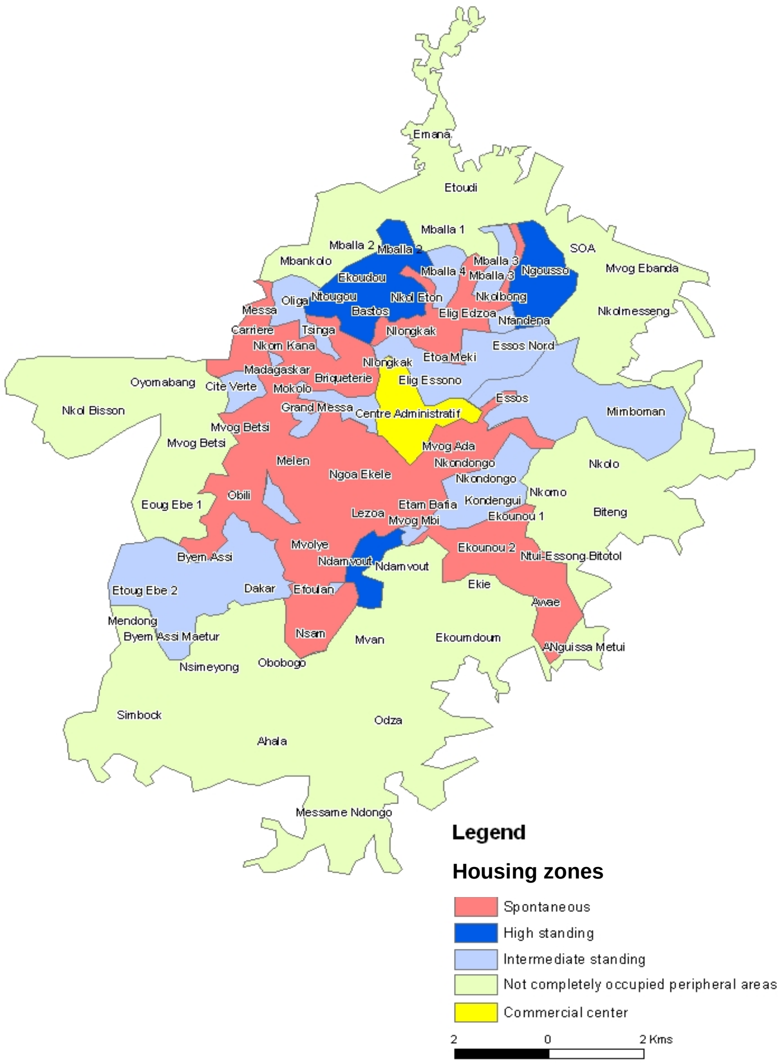


Figure 10: Distribution of the housing conditions in Yaoundé, according to the Yaoundé's Urban Community (Communauté Urbaine de Yaoundé (CUY), 2000)

Figure 11: Example of spontaneous habitat in Yaoundé (June 2007)

Intermediate standing habitats generally have basic accommodations; the large majority are legally installed. They may share their environment with both spontaneous and high standing habitats. Because of the scarcity of space in the non peri-urban zones, more and more are found in peri-urban areas. They share their environment with peasants (land owners) and other newly installed richer people with a higher living standard.

High standing planned zones correspond to places with full accommodations (paved roads, supermarkets, health care etc.). Identified aggregates of very high standing habitats are those where government high representatives and diplomats reside (see fig. 12).

Figure12: Houses in Bastos, a high standing area of Yaoundé (June 2007)

Yaoundé has one of the highest population growth rates worldwide (5.7% annually) (UNITED NATIONS, 2002). The total population was estimated at 2 million inhabitants in 2002 (United Nations, 2002). This population growth is spatially characterised by the colonization of the healthy forested green vegetation. It can be remarked that the ancient core of the city was situated in the north-west side of the city, with the dense habitat situated apart from the peripheral areas (see fig. 13). Rural and urban patterns overlap within the city. After the district of Mayo-rey in the north of the country, the district of Mfoundi has the most significant rate of population growth in the country. At the same time, it is the smallest district in the country, in terms of surface areas. Therefore, it has the greatest population density of the entire country, about 3,000 inhabitants per km^2. The demographic profile is similar to that of the quasi totality of SSA's countries and it is marked by a high presence of young people (see tab. 1).

Age	Males	Females	Total
0-4	81571	80855	162426
5-9	81318	82569	163887
10-14	76021	79193	155214
15-19	85576	98949	184525
20-24	99625	103251	202876
25-29	85538	81646	167184
30-34	60822	55445	116267
35-39	41339	39105	80444
40-44	35102	32241	67343
45-49	23492	19738	43230
50-54	16375	12951	29326
55 and more	23846	23649	47495
total	710625	709592	1420 217

Table 1: Population structure of Yaoundé by gender and age (After: INSTITUT NATIONAL DE LA STATISTIQUES (INS), 2002)

Yaoundé has been the capital of Cameroon since 1922. Formerly, it was a commercial centre managed by the German colonial administration. Because of its political status, the presence of strategic infrastructures (the city constitutes a nucleus in the national road and railway network,) and economic activities (informal and formal), it has a national and regional strategic importance. On the occasion of multiple economic (unemployment and agricultural crisis in rural and other cities of lesser importance) and political (instability in central Africa) crisis, the demographic pressure on the city is stressed.

Like almost all the SSA's cities of comparable size, the economic structure is mostly informal. It is estimated that more than 60% of the population of Yaoundé has an informal activity (KENGNE & BOBDA, 2000). 23% of the total population of the city is employed as civil servants which is the highest rate in the country (INSTITUT NATIONAL DE LA STATISTIQUE, 2002). It was estimated in 2002 that 24% of the city's active population was earning less than 282, 000 f. cfa (700 $) per year (INSTITUT NATIONAL DE LA STATISTIQUE, 2002). The general economic deprivation of the population is stressed by the inactivity of the political managers who are unable to provide a minimum assistance for their basic housing and health care needs. Social conditions seem to be optimal for a high vulnerability of populations to diseases. Among these diseases, vector-borne, notably malaria is well ranked. As stressed earlier, the presence of malaria in Yaoundé is not only related to favourable social factors but also ecological.

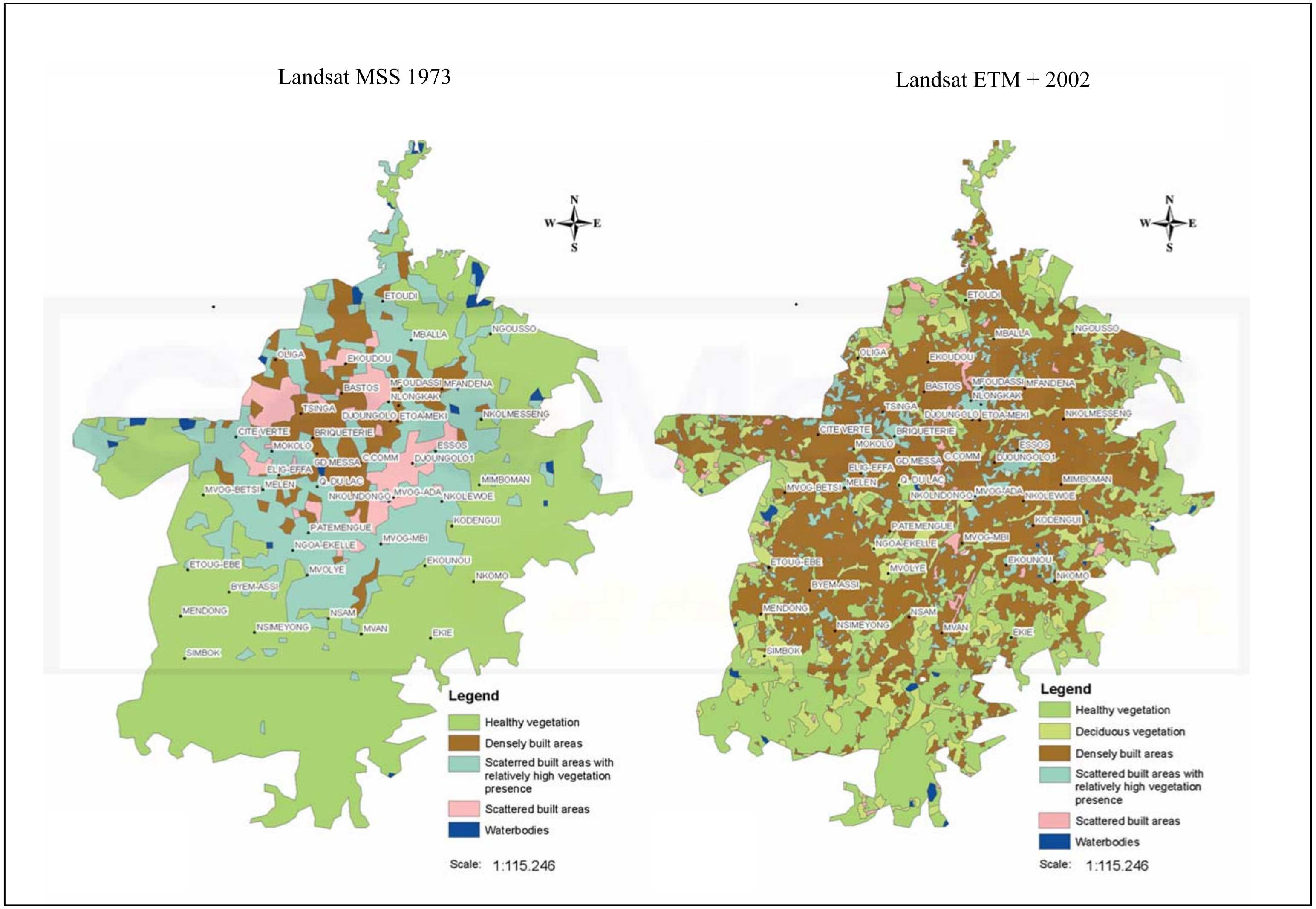


Figure 13: Yaoundé a rapid growing city (After NGOM & SIEGMUND, 2006 and 2007b)

2.5.3 Malaria-transmission in Yaoundé

2.5.3.1 Entomological findings in Yaoundé

Among the various vectors found in Yaoundé, *An. gambiae, An. moucheti, An. funestus* and *An. nili* are the most prevalent. Hammon and colleagues (HAMMON et al., 1956), observing the distribution and behaviour of *Anopheles* in Cameroon noted that *An. gambiae* preferred breeding sites are generally characterized by vertical not dense vegetation, or by the absence of vegetation, important sun radiation and by water not rich in organic materials. They stressed that *An. gambiae* liked temporary water pools, irrigation and drainage ditches, water leaks, and other artificial water pools like water tanks. Therefore, they concluded that *An. gambiae* was the predominant species in urban malaria.

An. Gambiae has been found in various sites in the city. Between March 1989 and March 1990, Fondjo and colleagues (FONDJO ET AL., 1992) conducted a compared base study in two areas of Yaoundé. They chose Nkolbisson, a peri-urban area in the north-west of Yaoundé. Nkolbisson was characterized by sparse settlement, the presence of a natural pond and the practice of urban agriculture. Among the species captured, 93% were *An. gambiae* and 3% *Culex quinquefaciatus*. *An. gambiae* aggressivity was permanent throughout the year with minimal values in dry seasons. The Entomological Inoculation Rate (EIR) was 32 bites/inhabitants/year. Because the yearly infection risk was important, it was nearly certain that the inhabitants who did not protect themselves against mosquitoe bites would have had one infected bite per year (FONDJO et al., 1992).

The second area chosen by Fondjo and his colleagues (FONDJO et al., 1992) was called Nkol Bikok which is the popular name of a sub-district situated between the districts of Melen and Grand Messa. This is a suburban, densely populated area where ecological features are less prevalent. *An. gambiae* constituted only 8% of the captured species while *Culex quinquefaciatus* constituted 91% of the total captures. Although permanent bites were observed throughout the year, *An. Gambiae* malaria-transmission was observed only during the month of May. The authors also concluded that inhabitants who did not protect themselves against mosquitoes' bites would have had one infected bite yearly.

Isabella and others conducted a similar study between 1994 and 1995 (ISABELLA et al., 2000). They also choose two sites marked by their ecological differences. Simbok is a peri-urban area having marked rural patterns (forested zone) and the presence of small pools of water throughout the year, while Etoa is more urban and has marshes and grassy bays in the Mefou and Beyeme rivers. In Simbok, they found 62% of *An. gambiae,* 23% of *An. moucheti,* 8. 3% of *An nili*, 5.1% of *An. funestus* and 0.3% of *An paludis*. 82% of average inoculation rate were due to *An. gambiae* 18% to *An. moucheti.* The parity rate of *An. gambiae* was 54 % that of *An. moucheti* was 62%, while the biting rate of *An. gambiae* and *An moucheti* were respectively 35% and 41 %. In Etoa, they found of 89.5% of *An. funestus*, 7.9% of *An. nili* 1.5% of *An. gambiae,* 0.9% of *An. moucheti,*, and 0.2% of *An. paludis*. The parity rate of *An. funestus* was 89%.

Manga and colleagues **(**MANGA et al**.**, 1993) conducted a study in two central districts of Yaoundé named Essos and Obili. The site chosen in Essos was a swampy valley where people were practicing urban agriculture (UA). The site chosen in Obili was a former aqua-cultural zone covered by aquatic plants. The anthropophilic culcidian fauna in Essos was composed with 84% of *Culex quinquefaciatus,* 9% *of mansonia* and 6% *of An. gambiae.* In Obili, the fauna was composed with 50% of *Culex quinquefaciatus* and 48% of *mansonia*. The EIR was 13 bites/inhabitant/year in Essos, highly concentrated within the small, rainy season. No *Anopheles* was found in Obili, thus no EIR was calculated for Obili.

2.5.3.2 Age and seasonal dependence of malaria in Yaoundé

People in Yaoundé are perceiving presence of mosquitoes as a major problem. The National Institute of Statistics (INS) conducted interviews in Yaoundé in 2002 (INSTITUT NATIONAL DE LA STATISTIQUES, 2002). People were questioned about the problems they had to face to in their environment. The problem of mosquitoes' presence was ranked after that of insecurity. But, when distributed according to the type of district (high standing, mean standing, peri-urban and spontaneous), the spontaneous, the high and middle standing districts types ranked mosquitoes as being the first problem (INS, 2000). This result does not mean that the presence of mosquitoes automatically expresses the presence of malaria. It simply means that there is a significant potential for vector presence and therefore for malaria presence.

Wethé and colleagues (WETHÉ et al., 2003) conducted a study on water management, socio-sanitarian and environmental hazards in planned habitat zones in Yaoundé. Their inquiries in hospitals and houses demonstrated the existence of high malaria prevalence among populations enjoying fairly acceptable life conditions. The results showed that most of the diseases present among the population were Water Related Diseases (WRD). Malaria was ranked at the top with 35% of cases. They did not identify an age group, particularly vulnerable to these diseases. They found a symmetric link between presumed febrile cases from households and clinical cases from health care deliveries.

Manga and colleagues measured the incidence of malaria based on the households' distances to swampy valleys in Essos and Obili. They made a longitudinal study based on blood tests. They discovered that the plasmodial index was higher in the small rainy season than in the big rainy season in Essos. They also discovered that the parasitic charge was higher among the under-five age group (MANGA et al**.**, 1993). These results are in accordance with those of Kolk and colleagues (KOLK et al., 2003). They conducted a cross sectional study in a central district of Yaoundé and concluded that the prevalence of high parasitaemia (>400 parasites/µl) and of gametocytes was seasonal. They also stressed that the prevalence of asexual parasitaemia and of gametocytaemias was age-dependant, with a potential infectious reservoir dominated by the age group 0-15.

3 Creating and analyzing malaria related data

3.1 A geoepidemiologic approach

One of the major problems in dealing with clinical studies in SSA countries is the lack of reliable data. In the case of Cameroon the ministry of public health is collecting clinical data from hospital reports. These reports are paper-based; they are not made on a regular schedule (this was personally been checked in some hospitals in Yaoundé). The bad local socio-political environment (corruption) does not permit easy dissemination of the data collected by the Ministry of Public Health. In any case, it was very difficult to obtain actual clinical data from the Ministry of Public Health.

Difficulties in obtaining data from the local authorities was only one of the reasons to get involved in a personal data-creation process for this research project. In fact, these data lack geographical information. Since many patients are coming from other rural and urban localities, the geographical location of hospitals or any other health center is not a guarantee of obtaining accurate spatial representation of malaria clinical cases. The data do not integrate the spatial component at the individual (household) level. The risk of "imported" malaria is high within these databases. In addition, the incomplete nature of these databases is not suitable for a broader exploration of the socio-economic/socio-ecological information that is required for clinical cases. Another handicap inherent in this data-gathering technique is related to the methodological biases: How can comparison groups be built up only from hospital cases and from various services (GORDIS, 2004)?

One alternative is to implement a cross sectional study where groups of people in the city would be subjects of a clinical follow-up process at their households (blood tests). Yet, even for a small part of the city, this method would be financially impossible to implement. Ethical assumptions would have constituted an important problem to overcome. Serious cautions on spatial validity of such a method would also have constituted a handicap. The same financial limits did not allow the realization of entomological inquiries. In fact, the first study design was supposed to synchronize clinical malaria follow-up with entomological surveys. The method finally used is a reliable alternative to all the cited limits.

3.2 Stratified random method

Households were considered as intermediate objects in the analysis, satisfying both spatial and socio-epidemiological requirements. The spatial requirements consisted of covering the entire city with assumed good possibilities for locating variability in malaria risk. The socio-epidemiological requirements dealt with inquiries at the individual level (individuals in a household). The aggregation of individuals at the household level permitted the assessment of socio-epidemiological as well as environmental conditions at a very high spatial resolution. A stratified random method was used. The random component is related with socio-epidemiological methodological requirements, while the stratification satisfies spatial requirements. In fact, it is assumed that population and environmental characteristics are not homogeneous within the districts of Yaoundé (ENIMELI et al., 2005, ASSAKO ASSAKO , 1997).

The procedures for conducting field inquiries were accomplished in collaboration with the Department of Geography of the University of Yaoundé I. Eight geography students were enrolled as interviewers. They received a short training course in GIS, particularly in how to make efficient use of the GPS. They also received a general briefing on malaria before going into the field. Three other students were enrolled for the regular control of the completed questionnaires.

The city was divided into equal squares, and random points (sector codes) were created inside these squares (see fig. 14 and fig.15). The idea was to randomly interview a minimum of four households around each of the random points. Once the final map of the code points for a sector was downloaded into the GPS, the interviewers were able to follow allocated sector code points in real time and randomly choose four households in a predefined radius around these points. Precise sectors codes were allocated to each interviewer's group.

Google Earth was used to visually evaluate zones where it was not plausible to find households. This human presence plausibility was indicated by communication networks-

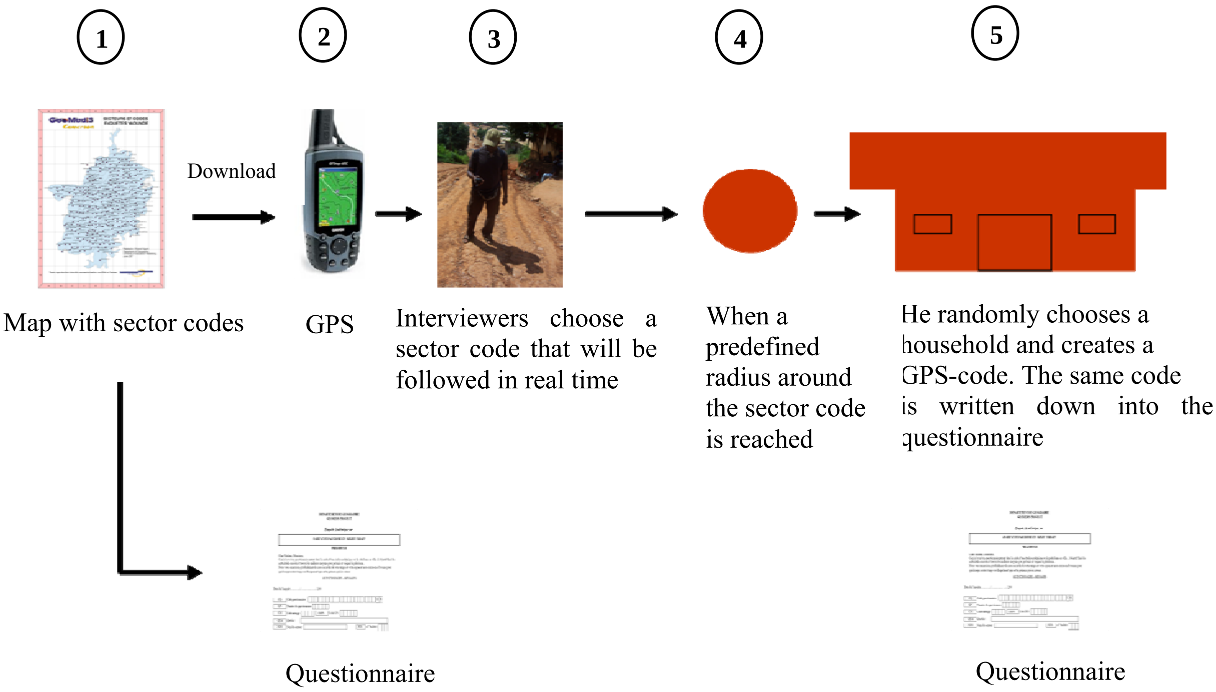


Figure 14: Description of the field data creation procedure (After NGOM & SIEGMUND, 2009[b])

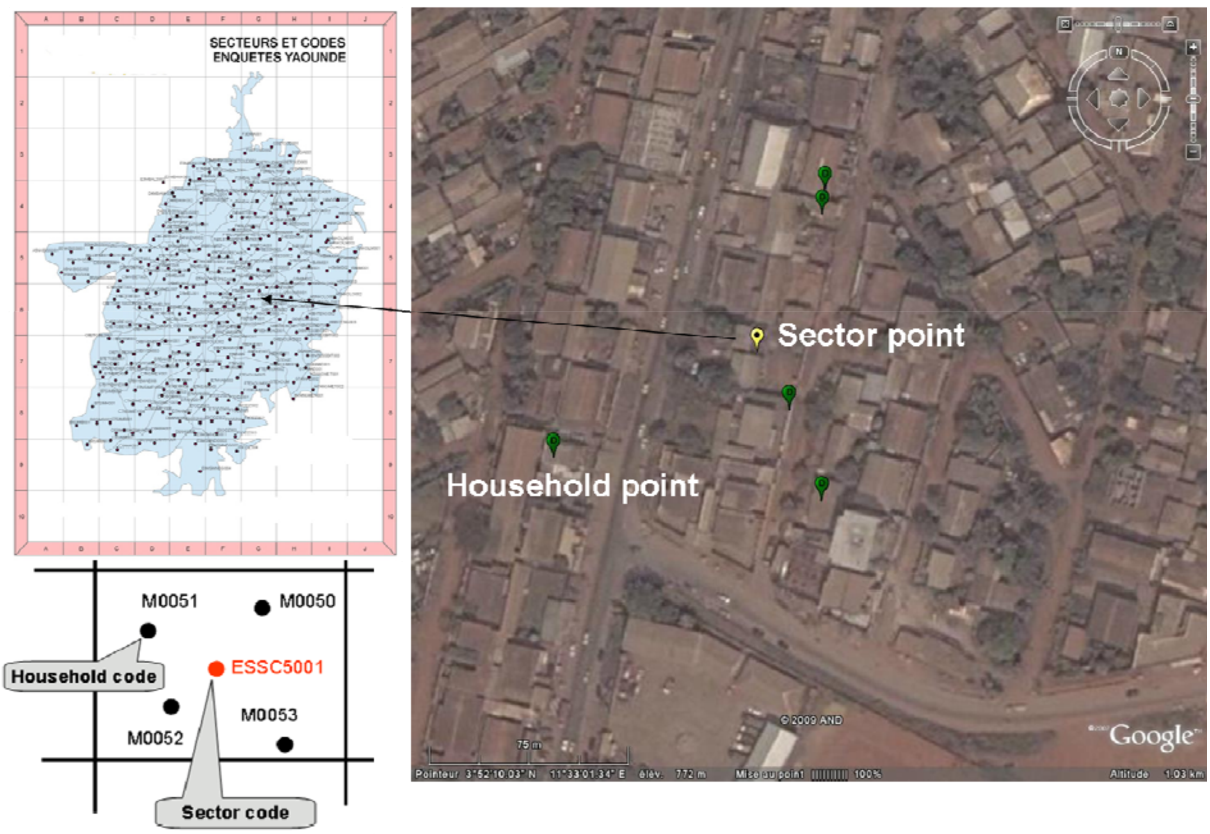


Figure 15: A stratified random method to gather geoepidemiological and geosocial data (After NGOM & SIEGMUND, 2009[a])

(roads, non-vegetated spaces). The geographical location of households followed a clearly defined coding protocol. The household code in the questionnaire was the same in the GPS (see fig. 14 and tab. 2). At the end of each interview session, the supervisor was able to download the newly measured households into Google Earth in order to visualize the accordance with the sector's code points previously allocated. In addition to this visual check, a systematic control of completed questionnaires was established to detect useless questionnaires. Sector points where questionnaires were subject to errors were covered again in order to maintain the spatial equilibrium. A total of 1, 925 households with almost 10, 000 individuals were covered by the end of the interview process. A very last control of questionnaires by the reviewers together with the supervisor led to the removal of 225 questionnaires from the set of 1,925. These questionnaires belonged to a previously separated group of questionnaires assumed to have minor errors, making them ineligible to be validated for inclusion with the properly completed questionnaires.

The process was thus retrospective and focused on the year 2006 (the field inquiries were conducted in June and July 2007). The questionnaire was concerned with a variety of socio-epidemiological and environmental questions (see tab.2 and appendix A). A noticeable place was given to febrile and clinical malaria cases in each household. Clinical cases were self-reported by the respondent. To classify a case as clinical, the interviewer had to insist on the question concerning eventual blood test and the results. Thus, it is the reported biological diagnosis from a laboratory that indicates if a case was definitively a clinical one. Although this method presented advantages from the spatial and logistical point of view, it obviously contained biases.

3.3 Bias removal and database strengthening

There exist several possible sources of errors in interviews surveys (GORDIS, 2004):

- The respondent may have the disease and may have had symptoms, but may not have had medical attention and therefore may not know the name of the disease.
- The respondent may not accurately recall an episode of illness or events and exposures related to the illness.
- The respondent may provide the information, but the interviewer may not record it or may record it incorrectly.

Since malaria symptoms are similar to those of many other local illnesses, one must make a caution on febrile reported malaria cases. Even in the case of clinical reported cases, pathogen presence is regularly associated with other illnesses such as typhoid and yellow fever (SARAH et al., 2003). The blood test itself does not guarantee a 100% malaria presence (WARHURST & WILLIAMS, 1996). For this reason, it is important to consider both the symptoms and the blood test. Malaria cases reported within this study are also probably subject to these errors.

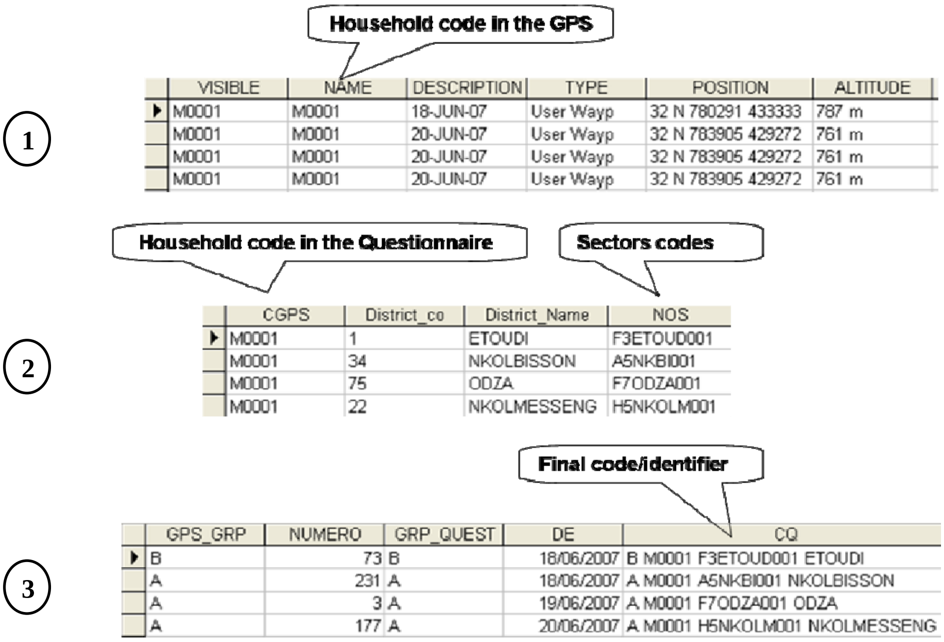
Another possible source of errors deals with the spatial artefact. It was not guaranteed that an individual that had malaria was infected at his living place during the reported period. There are three possibilities for that: a subject can be infected in another place prior to his installation to the actual reported living site, he can be infected during a visit in another place but in the same city (Yaoundé), and, finally, he can be infected during a travel outside of the city of Yaoundé.

In order to reduce the presence of some of these biases and to impose robustness to the final database, a series of crossed-checked questions designed to avoid confusions of febrile malaria symptoms with other probable non-malarial symptoms were added to the questionnaires. Another series of questions were included to allow for the removal of spatial biases relevant to the subjects' movements prior to their installation on the reported site. They also took into account the long stay of the respondent outside the site during the calendar period of the retrospective study (see tab. 2 and appendix A). With this process, risks of imported local malaria-transmission cases were considerably reduced, and the spatial value of the malaria outcome reinforced. From 1,700 households in the raw database, 1.408 households were eventually obtained after biases were removed. These requests were performed using Microsoft Access.

Code	Items
DE	Date
CQ	Questionnaire code
QN	Questionnaire number
CM	Household code
CGPS	GPS code
QUA	District name
NOS	Sector name
NUS	Sector code
B1AG	Age
B1SX	Gender
B1DIM	Month when installed on the site
B1DIA	Year when installed on the site
B 1PRMQ	Are coming from another place in the same district
B 1PRAQ	Are coming from another district
B 1PRVILLA	Are coming from a surrounding village
B 1PRAV	Are coming from another city
B1PRN	Name of the place from where you are coming
B1PM	Number of persons permanently living in the house
B4MIDI2006	At which month did you have malaria in 2006?
B4MIDI2007	At which month did you have malaria in 2007?
B4DVY	Did you travel before or after this period?
B4DVYM	At which month did you travel these years?
B4PE	Were you pregnant?
B4CM	For which period of infection did you have a clinical confirmation?
B4SPMT	Did you have headaches during this period?
B4SPFI	Did you have fever during this period?
B4SPFA	Were you tired during this period?
B4SPN	Did you have nausea during this period?
B4SPMF	Was your liver painful?
B4SPD	Did you have diarrhoea during this period?
B4SPMAT	What other symptoms did you have?

Table 2: Questions related to the epidemiology of malaria

After downloading GPS data and integrating information from the questionnaires into tables, it was possible to join each set of GPS data to its corresponding questionnaire via the household code. A unique identifier was then created for each household. This unique identifier was an aggregation of various items. The codification was differentiated according to the household's sector code, its GPS code, the interviewers' group, and the district name (see fig. 16).



VISIBLE	NAME	DESCRIPTION	TYPE	POSITION	ALTITUDE
M0001	M0001	18-JUN-07	User Wayp	32 N 780291 433333	787 m
M0001	M0001	20-JUN-07	User Wayp	32 N 783905 429272	761 m
M0001	M0001	20-JUN-07	User Wayp	32 N 783905 429272	761 m
M0001	M0001	20-JUN-07	User Wayp	32 N 783905 429272	761 m

CGPS	District_co	District_Name	NOS
M0001	1	ETOUDI	F3ETOUD001
M0001	34	NKOLBISSON	A5NKBI001
M0001	75	ODZA	F7ODZA001
M0001	22	NKOLMESSENG	H5NKOLM001

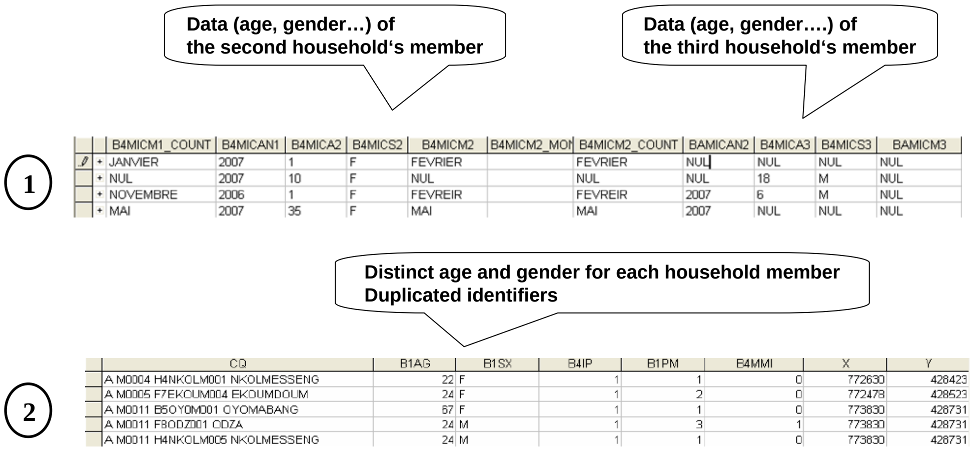
GPS_GRP	NUMERO	GRP_QUEST	DE	CQ
B	73	B	18/06/2007	B M0001 F3ETOUD001 ETOUDI
A	231	A	18/06/2007	A M0001 A5NKBI001 NKOLBISSON
A	3	A	19/06/2007	A M0001 F7ODZA001 ODZA
A	177	A	20/06/2007	A M0001 H5NKOLM001 NKOLMESSENG

Figure 16: Creation of a common identifier joining GPS and questionnaires data

Despite the inclusion of crossed-checked questions in the questionnaire, febrile malaria cases obviously remained subject to caution. As previously stressed, the necessity of distinguishing between malaria symptoms and symptoms of other illnesses maintained the uncertainty. In order to test the validity of reported febrile malaria cases, two statistical methods were used. The first one is concerned with the comparison of the monthly variability of both febrile presumed malaria cases and clinical malaria cases, on one hand, and comparison between all the cases (febrile added to clinical) and clinical cases on the other hand. The second method used bivariate analysis to evaluate the statistical association between the following three variables: total clinical cases, total febrile cases and total of all the cases (an addition of febrile and clinical). The synchrony in the monthly variation and the value and significance of the statistical association should lead to the decision whether to consider febrile cases or not.

3.4 Analysing age effect on malaria incidence

In malaria studies, age is a more important epidemiological determinant than gender. As stressed in the introduction, the under-five children are the most exposed to malaria. This demographic fact has an important impact on the prevention policies. On the other hand, and as stressed in the introduction, the epidemiology of urban malaria differs of that of rural malaria in many ways (CLYDE, 1987; BAUDON & SPIEGEL, 2001; BREMAN et al., 2004). A direct standardization method was used to evaluate age effect on urban malaria incidence in Yaoundé. Prior to this step, a new table was created from the last database. Individual cases clustered into households (households being the basic level of observation in the table) were extracted. These individual cases became the new observations level in the new table (see fig. 17).



	B4MICM1_COUNT	B4MICAN1	B4MICA2	B4MICS2	B4MICM2	B4MICM2_MOI	B4MICM2_COUNT	BAMICAN2	B4MICA3	B4MICS3	BAMICM3
+	JANVIER	2007	1	F	FEVRIER		FEVRIER	NUL	NUL	NUL	NUL
+	NUL	2007	10	F	NUL		NUL	NUL	18	M	NUL
+	NOVEMBRE	2006	1	F	FEVREIR		FEVREIR	2007	6	M	NUL
+	MAI	2007	35	F	MAI		MAI	2007	NUL	NUL	NUL

CQ	B1AG	B1SX	B4IP	B1PM	B4MMI	X	Y
A M0004 H4NKOLM001 NKOLMESSENG	22	F	1	1	0	772630	428423
A M0005 F7EKOUM004 EKOUMDOUM	24	F	1	2	0	772478	428523
A M0011 B5OYOM001 OYOMABANG	67	F	1	1	0	773830	428731
A M0011 F8ODZ001 ODZA	24	M	1	3	1	773830	428731
A M0011 H4NKOLM005 NKOLMESSENG	24	M	1	1	0	773830	428731

Figure 17: Gender and age extraction process from the database

A pyramid of the distribution of malaria cases per age and gender was obtained using the SPSS statistical package. The following direct standardization formula was used (1) and (2):

$$R_{As} = \sum_{i=1}^{i=I} \frac{R_{Ai}}{n_R} \qquad (1)$$

$$\text{with } n_R = \sum_{i=1}^{i=I} n_{Ri} \qquad (2)$$

where: i is the indicator of age group $\left(i \in [1; I]\right)$,

R_{Ai} is the specific incidence rate for the age,

n_{Ri} is the number of people per age group in the referent population,

R_{As} is the standardised incidence rate for the age.

The objective was to compare standardized incidence rate to the normal incidence rate in order to determine if age had an effect on malaria incidence. The referent population was taken from the National Institute of Statistics (INS) survey (INSTITUT NATIONAL DE LA STATISTIQUE, 2002). This is a socio-economic survey (total of 1,420,220 people) conducted in 2002. It describes various sets of socio-economic factors of the population. It is considered as being the most recent and reliable published socio-economic survey on Yaoundé (anonymous source from a statistician in the National Statistical Institute in Yaoundé).

3.5 Measuring the Malaria Relative Risk (MRR)

If disaggregated malaria cases are good for measuring global age and sex effects, they are not ideal for a spatially decorrelated representation (spatial redundancy/duplicates in points representation). For spatial requirements, households and their location were considered and used as the basic geostatistical element. This probably induces loss of information at the very finest individual (person) level, but, as already stated, it is a compromise between the ecologic and the biologic/epidemiologic approaches (see chapter 2.2.1).

Since many households were occupied by only a single individual, the calculation of a household's prevalence would have led to measurement errors. It would have overestimated malaria prevalence in these single occupied households. In fact, the denominator would consider multiple malaria episodes during the selected calendar period of 2006. It would have appeared that malaria prevalence is higher in households with single person than in those with many inhabitants, which would be an ecological error. This rule can be generalized and applied to households that can have the same number of malaria episodes but fewer inhabitants than others with the same number of malaria episodes but with more inhabitants. In order to avoid these errors, a malaria odds ratio indicating if the risk in a household is higher or lower than the mean risk of the survey was calculated. The following formulas were developed: (3) and (4):

$$Mh_i = \frac{m_i}{n_i} \text{ and } \overline{Mh_i} = \frac{\overline{M}}{\overline{N}} \tag{3}$$

$$M_{RR} = \frac{Mh_i}{\overline{Mh_i}} \tag{4}$$

where: i is particular household,
Mhi is the malaria ratio in a household ;
m_i is the number of malaria cases in a household i during the selected period;
n_i is the number of persons living in permanence in a household i during the selected period; $\overline{Mh_i}$ is the mean malaria ratio in a household for the entire survey;
$\overline{M}$ is the mean number of malaria cases in a household during the selected period in the survey; $\overline{N}$ is the mean number of persons living in permanence in a household during the selected period in the survey;
M_{RR} is the final Malaria Relative Risk (MRR) for a household.

3.6 Dealing with spatial outputs of geoepidemiologic variables

In the absence of a complete coverage of the city (within the administrative boundaries), spatial interpolation techniques using households as basic spatial inputs are reliable methods that allow a value estimation of spatially non-covered areas. Choosing an interpolation method greatly depends on the geostatistical configuration of the basic inputs. As previously stressed, the objective of the stratified method was to extensively cover the entire city. It has also been said that household's location by GPS was attributable to the presence of eventual households in the predefined sectors. This had an influence on the final spatial configuration of the input points (households). In fact, malaria-transmission can only occur where potential hosts exist (particularly human recipients). The spatial representativeness of the households finally included in the geostatistical analysis is visually acceptable (see fig. 18). A ratio of spatial representativeness of households at a district level was obtained using the following formula (5)

$$R_H = \frac{\overline{N_{Hd}}}{N_d} \tag{5}$$

where: $\overline{N_{Hd}}$ is the mean number of points per district,;
N_d is the total number of districts.

Ratios of representativeness of housing and vegetation were obtained by respectively using the following formulas (6):

$$R_{Hs} = \frac{\sum_{i=0}^{n} Hsi}{S} \quad R_{Vs} = \frac{\sum_{i=0}^{n} Vsi}{S} \tag{6}$$

Hsi represents the surface of housing obtained from a Land Use and Land Cover Classification (LULC) of a QuickBird image (see chapter 3.9);
Vsi represents the surface of vegetation objects obtained from a Land Use and Land Cover Classification (LULC) classification of a QuickBird image (see Chapter 3.9);

S is the total surface of Yaoundé's administrative boundaries.

The obtained R_H value was 24.33%. This is higher than the ratio of housing surface representativeness R_{Hs} (23% of the entire administrative area). This ratio is also inferior to that of vegetation representativeness R_{Vs} (37% within the entire administrative area).

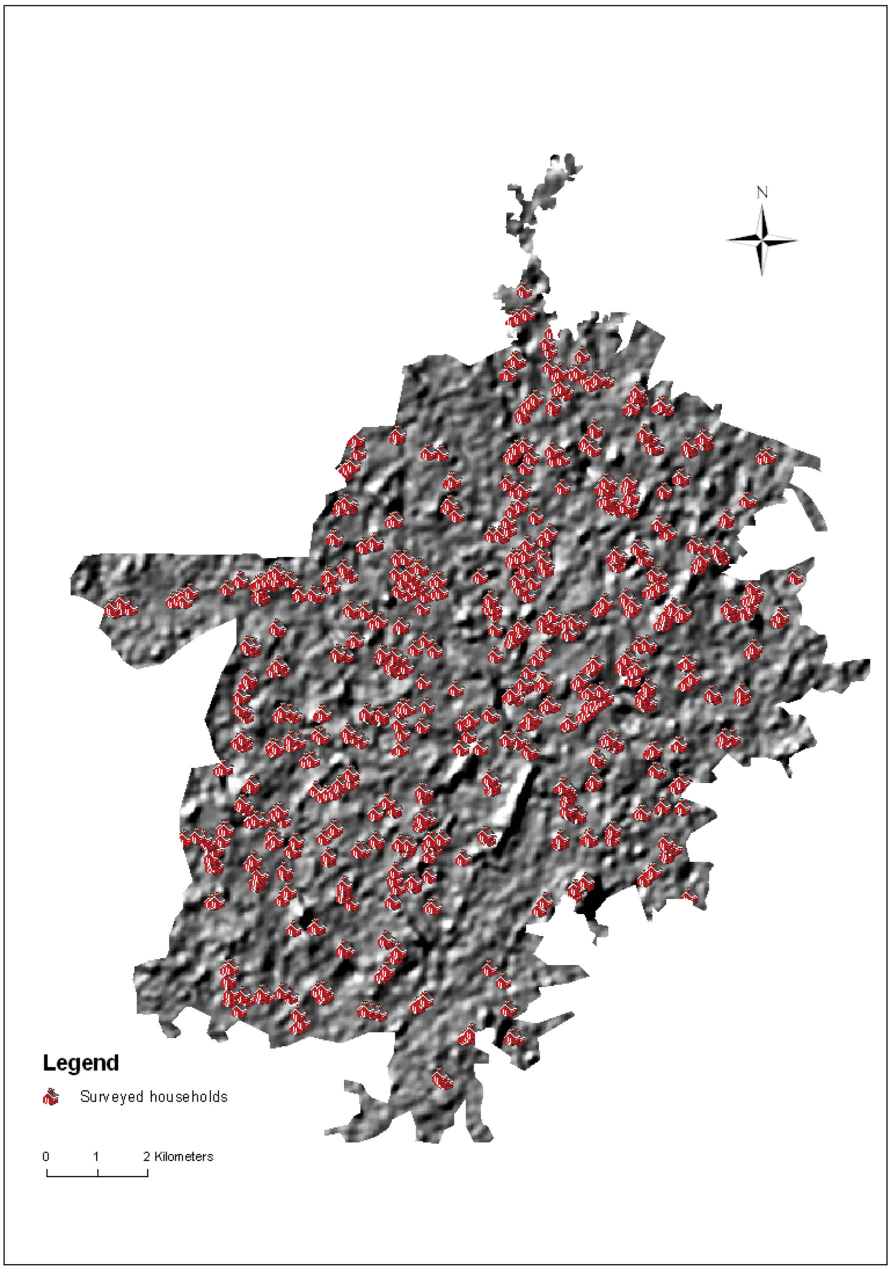


Figure 18: Final distribution of visited households

Visual and statistical evaluations of the spatial representativeness of the households were just steps towards the choice of an appropriate spatial interpolation method. They allowed the discrimination of methods that were not in accordance with the implicit methodological ultimate objective: obtain a surface representation that alters less the original input pattern. Thus, non-exact interpolations methods such as Global Polynomial Interpolation (GPI) and Local Polynomial Interpolation (LPI) were excluded. These methods produce smoothed results (BURROUGH, 1998) considerably altering the original pattern. Although being not

typically an exact interpolator method, the Kriging interpolation method was considered together with Inverse Distance Weighing (IDW) and the Radial Basis Function (RBF).
Since MRR data submitted to the interpolation were not following a Gaussian distribution shape, IDW and RBF appeared to be ideal methods, because they need no statistical assumption (BURROUGH, 1998; LUKASZYK, 2004). The Kriging method has the advantage of its flexibility; that means the measurement error model can be calibrated before the interpolation. A bootstrap approach integrating Kriging, IDW and RBF method was developed. The method consisted of sensitivity analysis and comparison of results between the three interpolation methods. First analyses were performed under the Geostatistical Analyst module of ESRI Inc. (Environmental Systems Research Institute). Households were randomly divided into two parts: a test data part with 985 points (70% of the survey) and a training data part with 423 points (30% of the survey). The training data points were submitted to the three interpolation methods. The resulting raster layers were used to extract values to test points. It was then possible to compare predicted values of the training data to real values of the test data (see fig. 19). Another comparison was based on multiple statistical criterions (see tab. 3, tab. 4 and tab. 5)

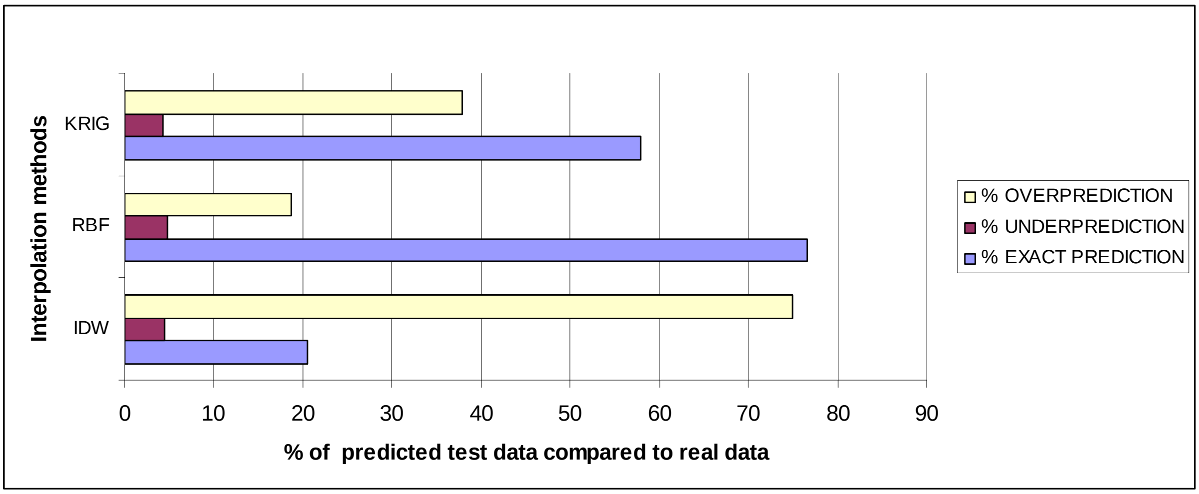


Figure 19: Comparison of the predictive performances of various types of spatial interpolation

Statistical values	**RBF**	**IDW**	**KRIG**
Skewness difference between measured and predicted*	0.68	1.27	2.17
Kurtosis difference between measured and predicted*	5.27	14.31	92.59
Standard deviation difference between measured and predicted*	1.12	1.45	-0.018
Error of prediction mean	0.018	0.03	0.095
Error of prediction variance	0.94	0.75	1.32
Spearman association value between measured and predicted at 95% CI	0.34	0.58	0,11

** In absolute values*

Table 3: Compared statistical results between measured and predicted values

Ranked variables	**KRIG**	**RBF**	**IDW**
Skewness difference between measured and predicted	3	1	2
Kurtosis difference between measured and predicted	2	1	3
Standard deviation difference between measured and predicted	1	2	3
Mean of prediction errors	3	1	2
Variance of prediction errors	3	2	1

Table 4: Ranking summary of interpolation techniques according to their statistical performance

	KRIG		RBF		IDW	
	Rank	%	Rank	%	Rank	%
Number of first position and percentage	1	20%	3	60%	1	20%
Number of second position and percentage	1	20%	2	40%	1	20%
Number of third position and percentage	3	60%	0	0%	2	40%
TOTAL	5	100%	5	100%	5	100%

Table 5: Ranking according to the statistical performance of each interpolation technique

Table 3 compares measured to predicted values. It shows some key statistical indicators of locators and variability in the data sets. Prediction errors were considered and differences calculated between predicted and measured statistical values. Table 4 shows a ranking of the interpolation methods according to their statistical performances. The lower the prediction error or the difference between predicted and measured values is, the higher the ranking. Table 5 is a summary of these performances.

Comparison between interpolation results from training data points and test data points showed a higher percentage of correct prediction resulting from the RBF technique (see fig. 19). The comparison of statistical outputs also showed a clear advantage of the RBF (see fig.4). In all the cases, RBF predicted values are the nearest to the measured values of MRR. This result allowed to finally consider RBF as the ideal interpolation method for the data set.

3.7 New indexes for contextually and statistically appropriated geosocial information

3.7.1 Individual/Household-based social and socio-ecological information

Social information were gathered together with epidemiological data and followed the protocol field interviews described in the previous chapter. However, there was a major difference related to the fact that for parts of the questions, interviewers had to contribute with self-observations. These items were concerned with the physical status of the house and its direct surrounding: roof material, wall material, presence of eaves, level of isolation etc. These questions were added together with questions of pure social or/and pure socio-economic nature (see tab. 6 and appendix A). Another important difference with the design of epidemiological questions is that some of the social information like employment were only addressed to the head of the household (see tab. 6 and appendix A).

Socio-economic	
Code	**Items**
B2NE	Level of study
B2AP	Professional activity
B2NR	Estimated monthly expenses of the household
Socio-ecologic	
Code	**Items**
AEH	Presence of vegetation, rivulets or well around the house
ATH	Housing standing
ATMT	Roof material
ATMM	Wall material
ATV	Type of vegetation
ATVA	type of vegetation (trees)
APA	Permanent presence of animals around the house
APC	How many rooms?
ATM	Evident gaps on walls
APP	Presence/absence of roof ceiling

AWC	External/internal toilets
AEOPO	Opened windows
AEOF	Opened doors
AEOPREG	Presence/absence of grids on windows
Prevention	
Code	**Items**
B1PM	Number of persons permanently living in the house
B3PM	How many people are sleeping under a mosquito net?
B3PMI	How many people are sleeping under a treated mosquito net?
B3AP	Do you prevent malaria by taking drugs in your family?
B3APF	At which frequency do you take drugs for preventive purposes?
B3IEI	At which frequency are you using insecticides
B3IEN	At which frequency are you cleaning the surrounding of the house
Malaria related knowledge	
Code	**Items**
B3TPM	Do you know what expose to malaria-transmission and how it is transmitted?

Table 6: Social variables introduced within the questionnaires

In the current study, socio-ecological variables are those focused on households. Their spatial primitive definition is a point originating from the GPS-positioning during the field inquiries. This spatial definition makes the difference with so-called ecological variables which, in their primitive spatial nature and origin are usually pixel-based (Chapter 3.7). The semantical definition of socio-ecological variables deals with physical elements of households such as walls, roof, eaves, type of toilets etc. They are mostly physical elements marked by a strong human impact. Ecological elements usually belong to more natural global processes, such as climate. As such, socio-ecological variables are easier to monitor and control (at a household level).

3.7.2 Deriving mathematical-based new geosocial information

New variables were derived from actual social and socio-ecological variables. By doing so, one of the goals was to create variables more adapted to the local context (a context of community life even in the same household). Another goal was to create indicators logically regrouping variables that belonged to the same sub-theme and therefore to reduce the complexity of the regression equation integrating these variables (see chapter 3.10). A third goal was to create variables that thematically expressed a better significance to malaria than the initial variables taken individually. A last goal was to quantify information that were mostly qualitative in their primitive nature, thus obtaining a scale of comparison with MRR as well as with other relevant variables. This data creation process was also supposed to ease the automation of the prediction.

<u>Coefficient of household crowding:</u>

The coefficient of household crowding is a calculation of the general crowding state of a household. This coefficient will determine the vulnerability of the inhabitants according to the level of crowding of their household. It considers the general architecture of the house as well as the type and quality of the material present. In fact, mosquitoes will be highly attracted by a type of material the house is made of, and less by another type. The architecture will determine the direct exposition of potential host to mosquito's bites. People living in houses with external toilets are potentially more exposed to mosquito's bites, simply because they usually get out in the night for their hygienic needs. The crowding coefficient was formulated as follows (7):

$$I_{hc} = R_c + wr_m + et + fb \qquad (7)$$

where I_{hc} is the household's crowding coefficient;
R_c (8) is the room crowding coefficient;
wr_m (9) is a variable describing the household's wall and roof quality;
et (10) indicates if toilets are physically outside the main building;
fb (11) indicates if the household belongs to a building with multiple floors.

The room crowding coefficient was formulated as follows (8):

$$R_c = \left(\frac{\sum_{i=1}^{n} n_i}{\sum_{i=1}^{n} nr_i} \right) \qquad (8)$$

where i is a particular household;
n_i is the total number of persons in a household;
nr_i is the number of sleeping rooms in a household;
the higher the number of rooms per persons in a household the smaller the room crowding coefficient value of this household.

The type and quality of walls and roof of a household was defined by the following formula (9):

$$wr_m = (wm + rm)^{gh} = \left(\sum_{i=1}^{4} wm_i + \sum_{I=1}^{3} rm_i \right)^{\left(\sum_{i=-1}^{1} gh_i \right)} \qquad (9)$$

where i is a particular household;
wm is a variable that classifies wall material according to their type and quality;
rm is a variable that classify the type and quality of the roof material;
gh is a variable that indicates the presence or absence of evident gaps or eaves on walls, roof or any other part of the house that can ease the mosquito's entrance into the house.
A higher value of wm indicates a better quality (hermetic, durable and sturdy). Walls made of fortified soil bricks were given the value 4, the value 3 was allocated to walls made of cement bricks. Walls locally called "poto poto walls", made with a mixture of mud, raphia palm tree materials and wood were given the value 2, walls made of wood or aluminium or a mixture of various unstable materials were given the value 1. The higher the quality of a roof, the higher the value of rm. Roofs made of tiles or intermediate roofs made of cements (cover slabs) were given the value 3, Roofs made of aluminium were given the value 2 while all the other types of roofs were given the value 1. The type of wall or roof material is an indicator of the general household crowding state. The value -1 indicates the absence of evident gaps or eaves while the value 1 indicates the contrary. The presence of gaps/eaves usually logically indicates the presence of bad walls and roof material quality. This relationship is characterized in the formula by the inversion of $wm + rm$ value with the -1 value of gh. Thus, the better is the material's quality, the lower is the wr_m coefficient value.

The position of toilets in a house was described by the following formula (10):

$$et = \sum_{I=0}^{1} et_i \qquad (10)$$

where i is a particular household and the value 1 of et indicates that the household has toilets that are outside of the main building.
This is also an indicator of the general crowding state of a household. Using such kind of toilets during the night exposes the inhabitant to mosquitoes' bites. The value 0 is allocated to households that do not correspond to the first description.

The features differentiating houses that were part of a building with many floors, to those that were not, were defined by the formula below (11). This variable determines the density of people at a particular point. This density has a potential incidence on exposition to malaria. Besides the fact that high densities (in a building) indicate presence of potential hosts, they probably contribute to the physical and chemical mechanisms that attract mosquitoes at a particular geographical point (building) (TAKKEN & KNOLS, 1999).

$$fb = \sum_{I=0}^{1} fb_i \qquad (11)$$

fb is a binary variable indicating if the household belongs to a building with multiple floors; the value 1 corresponds to households located in a building having two or more floors.

Coefficient of Economic Capacity:

The coefficient of Economic Capacity (EC) (12) measures the socio-economic level of inhabitants in a household as a whole and unique entity. It considers their monthly expenses on various vital and non-vital elements such as food, housing, telephone, clothing, transportation of all the household members. These elements were found more realistic than single incomes in a context of community life with cultural codes very different from that of western societies. Levels of expenses were simply divided into 6 classes during the interviews. Each class was then attributed an integer number (intervals of 1 to 6). The higher the integer value the higher the level of expenses. This coefficient was formulated as follows (12):

$$EC = \frac{e}{n}\,;\; EC = \frac{\sum_{i=1}^{6} e_i}{\sum_{i=n}^{n} n_i} \qquad (12)$$

where i is a particular household and

e_i is the monthly expense level of a household. The expenses include all the basic needs. n_i is the total number of persons in a household.

High expenses and low number of people in a household will indicate a high EC value.

Coefficient of prevention behaviour:

The coefficient of prevention behaviour (13) is a measurement of the level of protection of individuals in households, according to different complementary prevention methods. It is formulated as follows:

$$I_{pb} = Mu + EIG + df \qquad (13)$$

I_{pb} is the coefficient of prevention behaviour;

Mu (14) is a mosquito nets utilization coefficient;

EIG (18) is a coefficient related with utilization of insecticides, regular cleaning of surroundings and presence of grids on windows;

df corresponds to the frequency of drugs use (19).

The utilization of mosquito bed nets in a household was measured by using the following formula:

$$Mu = U_m + U_{im} \qquad (14)$$

Um (15) is a ratio of utilization of non-treated bed nets;

Uim (16) is an odds ratio of utilization of impregnated mosquito bed nets.

Thus, households that use insecticide-treated bed nets have a higher coefficient than those using non insecticide-treated bed nets. Households using neither treated nor non-treated mosquito bed nets have a Um coefficient value equal to 0.

The utilization of non-treated bed nets in a household was measured by using the following formula (15):

$$U_m = \frac{\sum_{i=0}^{n} nm_i}{\sum_{i=0}^{n} n_i} \tag{15}$$

where i is a particular household;
nm_i indicates the number of persons sleeping under a mosquito net in a household;
n_i is the total number of persons in a household.

The utilization of impregnated mosquito bed nets in a household was measured by using the following formulas (16) and (17):

$$U_{im} = \frac{\sum_{i=0}^{n} im_i}{\sum_{0}^{n} oim_i} \tag{16}$$

$$Oim_i = \frac{\sum_{i=0}^{n} im_i}{\overline{oim}} \tag{17}$$

where i is a particular household;
im_i indicates the number of persons sleeping under an impregnated mosquito net in a household;
oim_i (17) is equal to the mean number of persons sleeping under an impregnated mosquito net in a household over the mean number of persons sleeping under a non-insecticide-treated net in a household.

The coefficient related with utilization of insecticides, regular cleaning of surroundings and presence of grids on windows was measured by using the following formula (18):

$$EIG = \frac{\sum_{i=0}^{1} e_i + \sum_{i=0}^{1} i_i + \sum_{i=0}^{1} g_i}{3} \tag{18}$$

where i is a particular household;
e_i is a binary variable indicating if a household regularly cleans its surroundings;
i_i is a binary variable indicating if a household regularly makes utilization of insecticides;
g_i is a binary variable indicating if a household has protective grids on windows.

The regularity of the cleaning was evaluated within the selected calendar period of 2006. The reported values were based on a self-estimation of the interviewees. EIG values vary between 0 and 1, with 1 being the highest value.

The drug frequency coefficient was calculated using the formula below ((19) :

$$df = \frac{52}{\sum_{i=0}^{n} f_i} \tag{19}$$

where i is a particular household;
df corresponds to the frequency of drugs use by individuals in households.

df is divided into 3 calendar scales corresponding to various frequencies: weekly, monthly and yearly. The weekly frequency (with the attributed integer value of 1) corresponds to households where individuals have a drugs intake frequency of at least 3 times per month. Monthly frequencies (with gradual attributed values ranging from 4 to 48) are households where individuals have drug intake frequency of at least 1 time per every 11 months (with 11 months corresponding to 48 weeks). For a better understanding, a value of 4 will correspond to an intake frequency of 1 per month, while the value of 28 will correspond to intake frequency of 1 every 6 months (28 weeks). Yearly frequency (with the attributed value of 52) corresponds to households where individuals have drugs intake frequency of one time per year. The yearly period of 52 weeks is taken as numerator in the calculation. n_i is the total number of persons permanently living in a household during the selected calendar period of 2006. The more frequent the drug intakes, the higher will be the df coefficient value. The frequency of the drug intake was computed for the selected calendar period of 2006. The reported values were based on a self-estimation of the interviewees. The df coefficient does not consider parameters such as controversial effects of drugs intakes.

Coefficient of level of malaria-knowledge:

The coefficient of level of malaria-knowledge (20) measures the basic level of malaria-knowledge of individuals in a household it was formulated as follows:

$$I_{km} = \frac{w + v + h + m}{4}; \; I_{km} = \frac{\sum_{i=0}^{1} w_i + \sum_{i=0}^{1} v_i + \sum_{i=0}^{1} h_i + \sum_{i=0}^{1} m_i}{4} \tag{20}$$

where i is a particular household,

I_{km} is the coefficient of level of malaria-knowledge;

w, v, h, m are binary variables respectively indicating if the subjects in a household know anything about the role of water, vegetation, biting hours of mosquitoes and the fact that malaria is caused by a mosquito.

The I_{km} coefficient value will vary between 0 and 1, with 1 being the highest value.

3.8 Collecting and analysing ecological data

3.8.1 Ecological not individual

What is defined in this study as being ecologic variables should be distinguished from individual/household-based socio-environmental and socio-epidemiologic variables previously described. In this study, ecological factors were defined as being physical elements not spatially referring to individuals/households in their primitive nature (HAUG, 1977; MACYNTIRE et al., 1996; DIEZ-ROUX, 1998; BERKMAN & KAWACHI, 2000). They are generally pixel-based data due to their sources (remote sensing). The difference with individual/household based elements is not only spatial, it also deals with conceptual approaches. These conceptual approaches can be differentiated according to the processes and elements that fashioned the identified ecological factors.

The first approach considers active natural physical elements and processes belonging to more global processes. In this scope, biotope elements such as climate, hydrology and natural vegetation were considered. The second approach refers to human ecology; it identifies physical and structural urban elements related with the macro economic dynamism of the considered urban society (BRONFENBRENNER, 1979; GROSS, 2004). In a multilevel definition, they are macro spatial elements that can impact on micro physical entities (individuals/households). The nature of this impact can be social (urban communities, living standards inequalities), in the sense that the urban morphology will define the relationship of individuals/households to a social category (SUSSER et al., 1985). The impact will also be biological/epidemiological (biological vulnerability) (LAST, 1998) in the sense that differences in morphostructures will reflect differences in communities' biological vulnerabilities. In return, these micro spatial entities (individuals/households) generally do not have the possibility to define the morphology and the evolution of the global structure to which they belong, although they act on it unconsciously. This last statement is particularly true for SSA countries. Land Use and Land Cover (LULC) factors are part of these so called macro socio-ecologic elements.

The relationship of ecologic elements (natural elements) with malaria-transmission risks was defined in the first chapter: rainfall, temperatures, elevation, slopes, relative humidity, water bodies, distance to vegetation, Normalized Difference Vegetation Index (NDVI), distance to UA areas, city's introduced in ecological analysis. Built-up structures (buildings aggregates) and urban-rural fringe are the macro-ecological elements not directly relating to the natural biosphere. They were also introduced in the analyses.

3.8.2 Ground-based and rainfall estimates data

Various sources of climate data were integrated into this study. Climate data from two ground stations situated within the administrative limits of Yaoundé were considered. The station of Nsam Efoulan situated in the military airport, but managed by the Ministry of Transport, and the station of Nkolbisson managed by the ministry of scientific research and innovation through the Institut de Recherche Agricole pour le Développement (IRAD) (see fig. 20). There exists no other officially known station within the city. The distance between the station of Nsam Efoulan and the station of Nkolbisson is 8 km. The station of Nsam Efoulan is the oldest one. Data are collected in this station since more than fourty years. This is a non-automatic climate station allowing the measurement of rainfall, temperature, relative humidity and wind direction. The poor spatial network composed by these ground stations did not allow a credible spatial coverage of the city. In fact, the hypothesis of intra spatial micro-variability is not assumed here (see Chapter 1).

Historical climate data from 1990 to 2000 in addition to daily and monthly data of the year 2006 were considered for the station of Nsam. The relative recent installation of the other station only allowed considering daily and monthly data of 2006.

Because of the spatial limitations of the ground station network, another climate data source type was considered. Rainfall estimates (RFE) are obtained from a combination between geostationary satellite data and ground stations data. The latest algorithm uses the Cold Cloud Duration (CCD) data derived from cloud top temperature version and station rainfall data. Meteosat 7 infrared data are acquired in 30 minute intervals, and areas depicting cloud top temperatures of less than -38.15° C are used to estimate convective rainfall. The World Meteorological Organization (WMO) Global Telecommunication System (GTS) data from about 1000 stations provide station rain gauge totals and are taken to be the true rainfall within 15 kms radii of each station. Two new satellite rainfall estimation instruments were incorporated into this last algorithm, namely, the Special Sensor Microwave/Imager (SSM/I) on board Defence Meteorological Satellite Program (DMSP), and the Advanced Microwave Sounding Unit (AMSU) on board National Oceanic and Atmospheric Administration (NOAA) satellites. SSM/I estimates are acquired at 6 hours intervals, while AMSU rainfall estimates are available every 12 hours. The final daily rainfall estimation is obtained using a two part merging process, and then daily totals are summed to produce decadal estimates. All satellite data are first combined using the maximum likelihood estimation method, then GTS-station data are used to remove bias (XIE & ARKIN, 1997).

The final product that can be freely downloaded from various websites has a resolution of 8 km. Dekadal rainfall estimates (RFE) maps from January 2006 to December 2006 were downloaded and aggregated into monthly values maps. It was possible to extract RFE estimates for household and for ground stations in the database, using geoprocessing tools in ArcGIS.

The hypothesis of an important spatial intra variability of climate data is considered in advance as one of the added values of this study. As previously discussed in the introduction, most of the existing geomalaria models are based on climate predictions at a continental level. It is therefore obviously not realistic to expect information at a finest intra city level. An important point in using available climate data was to check whether they can allow subsequent analysis at this very spatial intra city level. The first step consisted of a comparison between ground station data and RFE data. In the second step, the spatial variability of ground stations was evaluated in regard to the variability of their micro ecosystem. In a third step, climate values variability was compared between the stations. A last analysis consisted of comparison between historical climate values and 2006 values. The purpose was to evaluate the robustness of the actual values of 2006 and their significance to the variation of malaria prevalence.

The comparisons between ground station rainfall data and RFE data were made on the basis of their graphical representation, and from bivariate analyses under Stata. The comparison between historical and 2006 calendar data followed the same methodology. In order to make a brief analysis of the micro ecosystem of the ground stations, their direct surrounding ecological conditions were considered. A buffer of 500 m radii was created around each station. These buffer polygons were then transformed into points features (see fig. 20). It was possible to extract topographical, NDVI and malaria relative risk values to these points. For the final stratified comparison between the two points, only the mean values were considered.

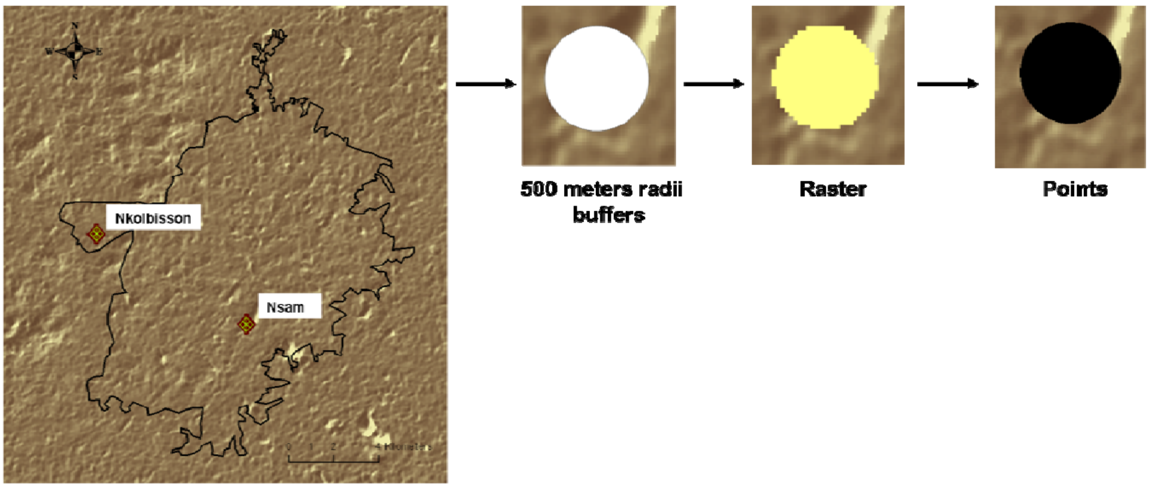


Figure 20: Location of climate stations within administrative boundaries, and procedure of the creation of geostatistical climate survey

3.8.3 Hydrological modelling approach

While rainfall is an indirect indicator of mosquitoes breeding sites potential presence, hydrological features such as water budget are more direct indicators. At the same time physical and chemical characteristics such as the stream velocity, the degree of water pollution and turbidity could intervene in order to moderate the potential impact of hydrology in favouring breeding sites presence. In a certain manner, calculation of precise water budgets is too complex and imprecise for an urban environment (VAN DE VEN, 1990, URBONAS & ROESNER, 1993). During the modelling process of hydrological factors, complex elements such as soils types, soil permeability, water velocity, water pollution, water evaporation and evapotranspiration were not considered.

Various approaches were considered in building a hydrological model. The first approach stressed on a detailed hypothetical presence of streams. Hypothetical water stream links are represented by a grid, which indicates the length, in meters, from each cell in the grid to the outlet, following the path the water would take (see fig. 21). Raw Digital Elevation Model (DEM) is used to create a flow direction and a flow accumulation grid under the software module ArcHydro of ESRI. Raster calculator in the software module Spatial Analyst is then used to create a drainage grid that represents cells in flow accumulation grid having two or more cells contributing to the runoff. A weight grid representing the time in seconds that the water takes per meter to traverse a cell in stream and overland respectively is then created. In a last step a flow length grid is created using the flowlength command in Raster calculator.

In order to evaluate the potential impact of these hypothetical streams, multi buffers with gradual distances (0-600 m) were created along the streams' polylines. A distance to stream link value was extracted to each household (points). All these geoprocessings were performed in ArcGIS. It was possible to statistically evaluate the relationship between these hypothetical water streams and Malaria Relative Risk (MRR). This bivariate analysis was performed using Stata statistical package.

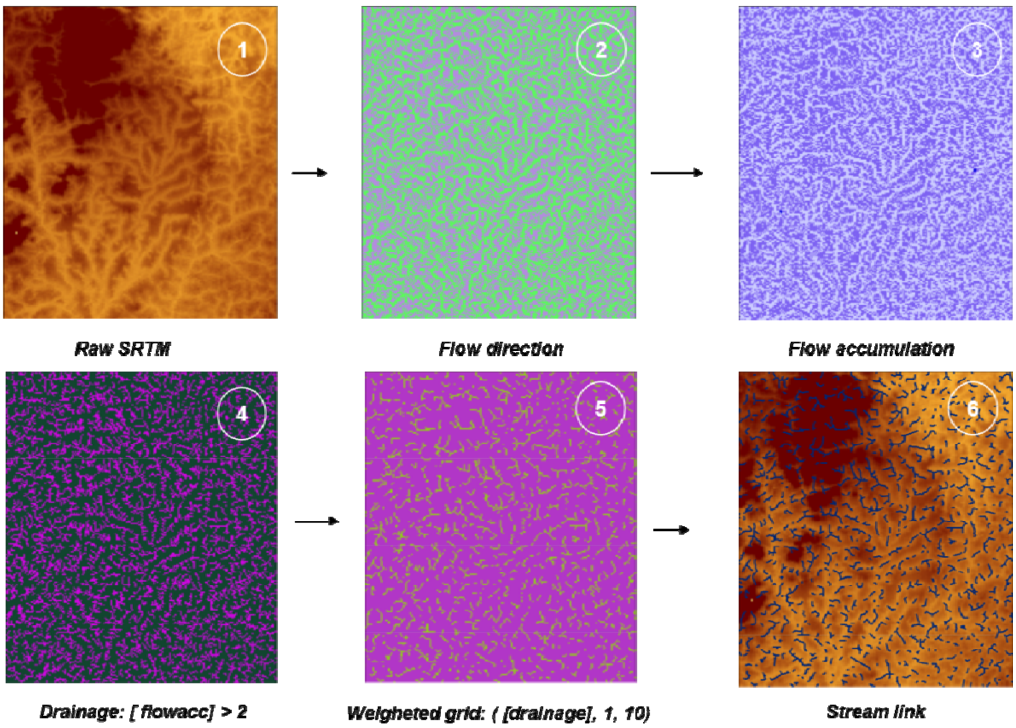


Figure 21: Steps in the creation of hypothetical streams

A less dense and less detailed drainage system was created using ArcHydro extension under ArcGIS. The recently created flowdirection and flowaccumulation grids were used as input to delineate watersheds and stream network. A new grid containing the basic characteristics of the future streams was created using the Stream definition tool under ArcHydro. This new grid used the Flowaccumulation grid as input. A threshold drainage area of 4.5 km^2 was defined and introduced for stream determination. The flow accumulation grid and stream definition grid have then been used to segment the streams. This was done with the stream segmentation tool of ArcHydro. The Flowaccumulation grid and the segmented streams grid were used as inputs to delineate catchments (see fig. 22).

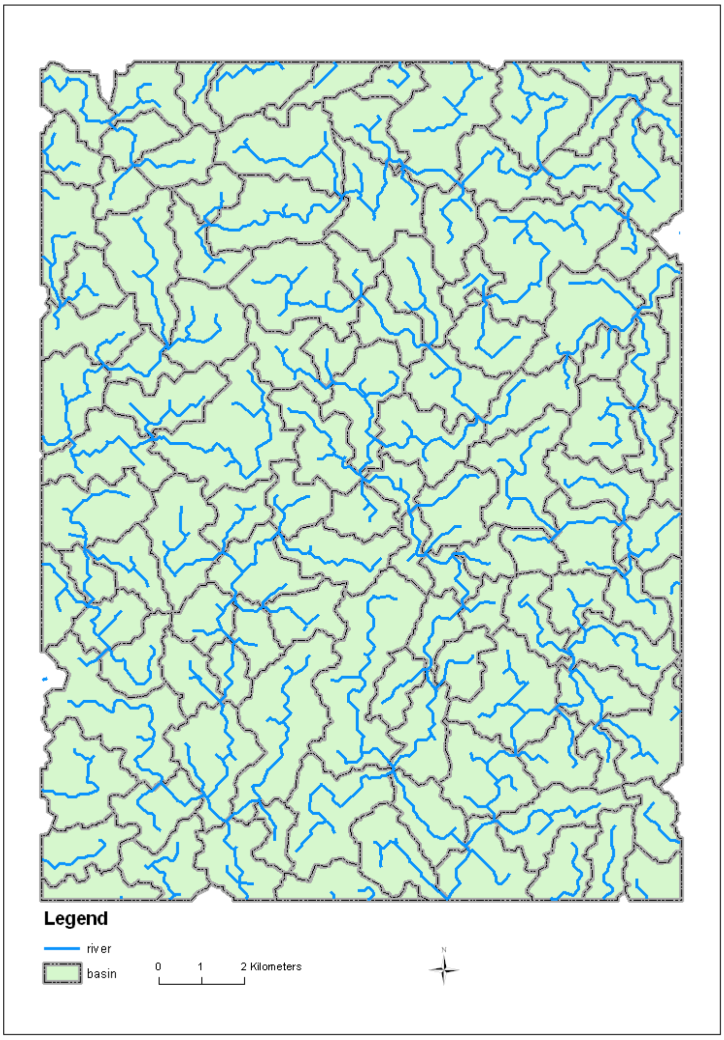


Figure 22: Catchments and rivers of Yaoundé

Besides DEM from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) and GDTOPO, pansharpened images of QuickBird (see Chapter 3.9) were used as an additional source of hydrological data. A pansharpened QuickBird image of Yaoundé with 0.6 m of spatial resolution was used to digitize water features in the form of polylines. As previously reported, the less dense stream network obtained with ArcHydro was introduced and used as visual support to detect presence of potential streams. Additional water bodies features (polygons) were obtained from a classification process using the same

QuickBird image (see Chapter 3.8.4). Artificial swimming water pools in high standing private properties were excluded from this extraction process.

3.8.4 Remote sensing analyses

There is a lack of updated morpho-structural information of social relevance concerning Yaoundé. To consider remotely sensed information sources is the cheapest and most practical way to obtain such information. There exists official cadastral information that are incomplete and not updated. The last known date of such a cadastral map obtained with these information sources is 2002 (COMMUNAUTÉ URBAINE DE YAOUNDÉ, 2002). The uncontrolled growth of the city makes this information hardly impossible to manage properly. The typical informal growth process added to various more or less controlled urban zones gives rise to various morphological patterns within the city. These patterns could reveal major social or community factors. Identifying and describing these patterns are key steps in understanding urban malaria spatial patterns. The classification of remote sensing data is the fundamental step towards this identification.

3.8.4.1 An object-oriented classification

Landsat ETM+ data 2002 and ASTER data from 2007 were used to obtain LULC features of Yaoundé. Various classification techniques were used in order to classify these data. Although these classification processes gave important results (see fig. 13), the spatial resolutions of the data sources were not high enough to allow a more accurate analysis of the features of the city. The statistical evaluation of the quality of the classification of various types of built-up areas was not reliable. Thus, the morphology of the city according to these classifications was too general and inaccurate to allow further socio-spatial analysis. It was, for example, impossible to estimate the population of the city and to realize all the analysis related with the various distributional patterns of this population. Because of all these shortcomings, another classification was performed, using QuickBird data. QuickBird data were precisely chosen because of their very high spatial resolution (see tab. 7)

Multi spectral bands	Spatial resolution	Spectral bandwitdth
Blue	2,4 m	450-520 *nm*
Green	2,4 m	520-600 *nm*
Red	2,4 m	630-690 *nm*
Near Infrared	2,4 m	760-900 *nm*
Panchromatic band	0,6 m	450-900

Table 7: Spatial and spectral resolution of QuickBird images

The problem with remote sensing imagery of the equatorial zone is that they are usually very cloudy. This high cloudiness makes it difficult to choose data according to an appropriated period. In the case of this study, the ideal selected period is the year 2006. This year is, in fact, the one used to collect social information. However, it was difficult to obtain a complete scene with a satisfactory percentage of cloud cover within the year 2006. Archive data were finally considered. Four scenes were chosen; they were all corresponding to the month of January (dry season) with interval dates between 2005 and 2008 (see tab. 8 and fig. 23). The idea was to use these data as a proxy to the selecter referent calendar period of 2006. It is assumed that the change is not important enough between 2005 and 2008 to allow critical variations within the data. However, when mosaicking these data, the one with the extreme dates of 2005 and 2008 were not given priority. Because of data redundancy, one of the scenes was finally excluded from the mosaicking process (see fig. 23).

Scene number	Product	Sensor vehicle	Aquisition date	Acquisition Time	Acquisition Season	Cloud cover Percentage
1	Quickbird	QB02	09 January 2007	10 03' 28 ''	Dry season	37%
2	Quickbird	QB03	14 January 2007	10 08' 51''	Dry season	7%
3	Quickbird	QB04	12 January 2008	09 59' 47''	Dry season	24%
4	Quickbird	QB05	11 january 2005	09 41' 53''	Dry season	1%

Table 8: General Characteristics of QuickBird images

The data were already orthorectified, but a georectification was applied with the help of GPS-data taken in Yaoundé. After the georectification, it was possible to mosaic the scenes (see fig. 23). These operations were performed under Erdas Imagine. The objective of the mosaicking was not only to join all the scenes into one, but also to cut them and mix them in a manner that the final mosaicked scene would be the least cloudy possible (see fig. 23). The cutlines and all the algorithms used to mosaick the multispectral images were used as well to mosaic the panchromatic images. Neither color balancing nor histogram adjustments were applied. The idea was to keep the original spectral values of the data.

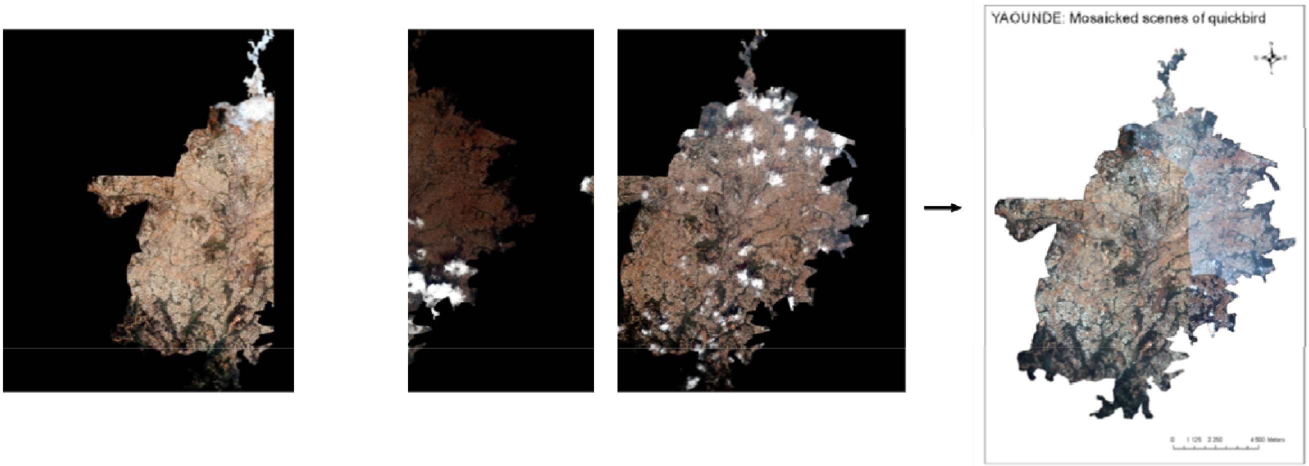


Figure 23: Chosen scenes of QuickBird and mosaicked image of Yaoundé

Before making the classification of the mosaicked image, a data-fusion of panchromatic and multispectral image was made. The objective was to obtain a better visibility of the features, which would help in a visual evaluation of the classification. This data fusion was performed under ArcGIS 9.3 using the Brovey algorithm. The Brovey-transformation is based on spectral modelling and was developed to increase the visual contrast in the high and low ends of data's histogram. It uses a method that multiplies each resampled, multispectral pixel by the ratio of the corresponding panchromatic pixel intensity to the sum of all the multispectral intensities. It assumes that the spectral range spanned by the panchromatic image is the same as that covered by the multispectral channels (BEAUCHEMIN et al., 2002).

Since the data were physically defined with 16 bytes radiometrical resolution, the quality of the results was visually good (see fig. 24). Because of the spectral alterations caused by the fusion process, the obtained pansharpened image was not used for the classification.

Figure 24: Multi-spectral (A) and pansharpened (B) images of QuickBird

At the difference of other image classification methods, the object-based geometrical/topological processing units are image objects or segments, not single pixels (BAATZ et al., 2000; KRESSLER et al., 2003). Even the classification acts on image objects. By using this technology, the expectation is to extract real world objects, proper in shape and proper in their semantic representation. The method does not only allow spatial aggregations of pixels to image regions, but also a semantic structuring of the image content. The object will be defined by its geometrical/topological and thematic/semantic characteristics. This is made possible by a segmentation process and a Fuzzy Logic-classification approach.

The segmentation is the process by which distinct segments/images-objects are obtained from an image. Segmentation is a key concept in object-based classification. The basic object shapes will be largely defined by the segmentation process. Heterogeneous regions can sometimes favour over or under segmentation. An over segmented object can further be integrated into another class (object) with a better semantic significance while an under segmented object can be segmented again (class hierarchy). This allocation of segmented objects in the classification process is not only based on the topology of the objects, it also considers semantic features (spectral). This is allowed by the integration of soft classifiers in the classification process (at least in the case of the software eCognition).

It is argued that the most powerful soft classifiers are based on Fuzzy-systems (FISCHER & GOPAL, 1996; FOODY, 1996). Fuzzy Logic is a mathematical approach to quantifying uncertain statements. The fuzzification process will describe the transition from a crisp system to a Fuzzy system. It assigns the membership degree (membership value) between 0 and 1 to each feature value. Fuzzy classification systems are well suited to handling most vagueness in remote sensing information extraction. In a Fuzzy classification, the membership degree to each LULC class is given for each object. Thus, object-based classification methods are suitable for urban areas such as Yaoundé, which are assumed to be very heterogeneous (ENIMELI et al., 2005).

The final classification was performed using eCognition. One of the most interesting functions of this software is the possibility to use multi-sources data in the segmentation and classification process. The panchromatic higher spatial resolution data were introduced and used in the segmentation procedure together with multispectral data. Several multiresolution segmentations were performed until a visually acceptable result was reached. The visual evaluation of the results was made with the help of pansharpened data.

A knowledge-base was then created using the class hierarchy tool. Seven classes were created (see tab. 9), but only six were maintained for the final analyses. Features of classes were described according to the mean spectral value of the classes in histograms (see fig. 25). The higher the mean value in a histogram's band (multispectral bands) was, the higher were its chances to be integrated in the concerned feature membership. The idea was to consider only bands that were clearly making a distinction between the selected class object and the other classes. In doing so, class overlappings were avoided. Because of the fact that buildings' roofs do not necessarily have an identifiable geometric shape in Yaoundé, it was hardly difficult to consider object shapes in the description of the feature class. Bare soils and buildings' roofs were very similar in their shapes and spectral values. In fact, many buildings were covered with dust at the moment at which the image was taken (dry season).

N	Class names
1	Vegetation
2	Natural water bodies
3	Paved roads
4	Bare soil
5	Housing roofs
6	Clouds
7	Stressed vegetation

Table 9: Classes introduced in the class hierarchy

A classification using membership functions was performed with no visual and statistical satisfactory results. This was largely caused by the confusion between bare soils and buildings' roofs. A second Nearest Neighbour-classification was performed with better visual and statistical results. The utilization of Nearest-Neighbour evaluated the correlation between object features favourably. Overlaps between bare soils and buildings' roofs in the feature space were handled much easier with the Nearest-Neighbour classification. Image objects that were not assigned to a class or that were incorrectly classified were chosen as additional samples to improve the classification result. This pairwise processing method, although consuming more time, allowed a better classification result. Classification results were visually and statistically evaluated. The statistical evaluation was made by producing best classifications, error matrix tables (see tab. 10 and 11) (LILLESAND & KIEFER, 1987).

Class	Objects	Mean	StdDev	Minimum	Maximum
Vegetation	514143	0.98422348677	0.019629781394	0.10157715529	1
Natural water bodies	270	0.99539802472	0.011534943923	0.85001593828	1
Paved roads	85838	0.98727350384	0.016571548572	0.42017534375	1
Bare soil	149909	0.97424847873	0.026274161887	0.36043065786	1

Housing Roofs	377711	0.89418658627	0.14796402838	0.10025851429	1
Clouds	13902	0.77335244492	0.24854549932	0.10068706423	1

Table 10: Best classification results from eCognition

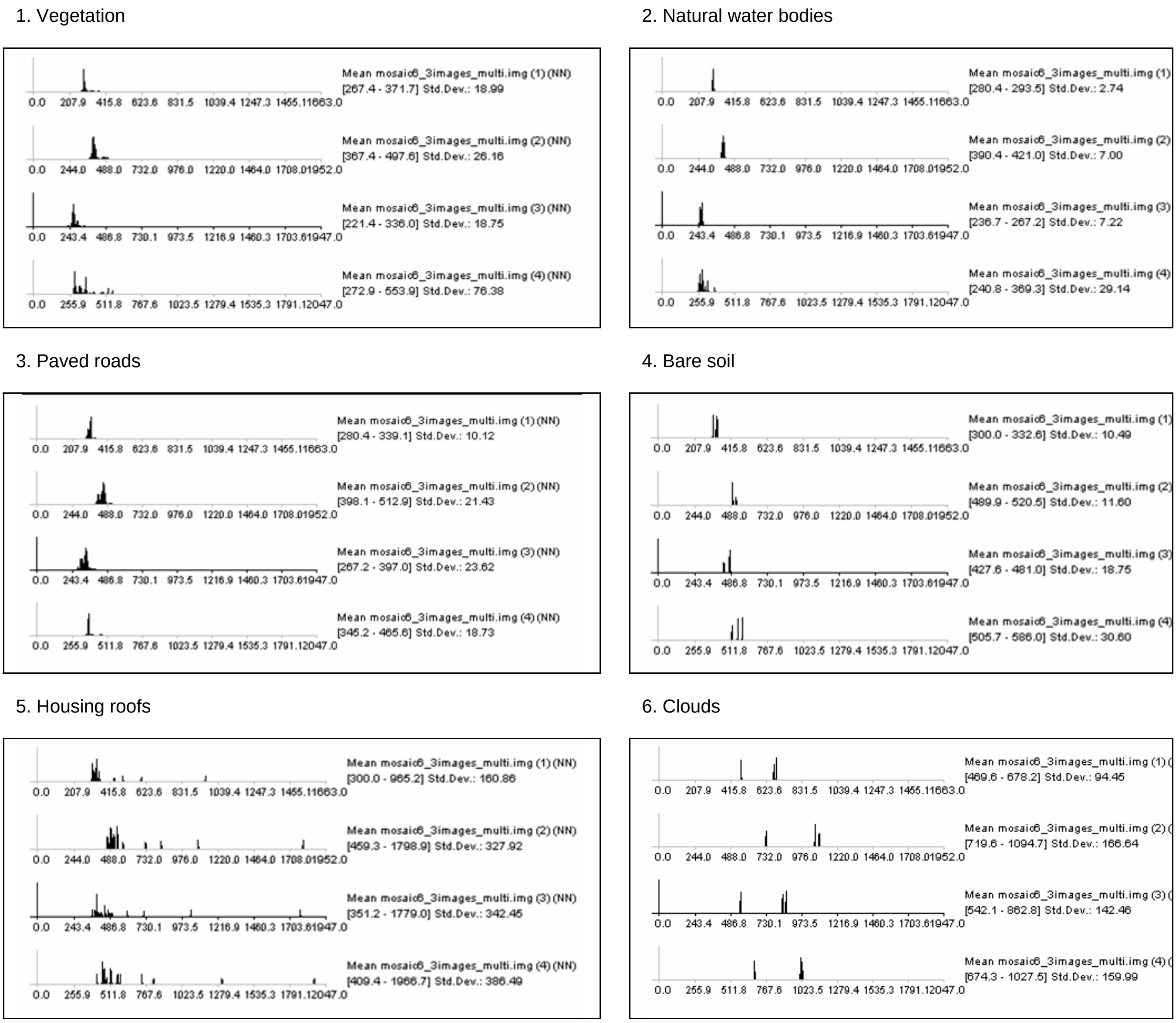


Figure 25: Histograms of QuickBird data defining mean values of class features in each band

Confusion matrix						
User Class \ Sample	Vegetation	Natural water bodies	Paved roads	Bare soil	Housing Roofs	Clouds
Vegetation	35	0	0	0	0	0
Natural water bodies	0	15	0	0	0	0
Paved roads	0	0	56	0	0	0
Bare soil	0	0	0	3	0	0
Housing Roofs	0	0	0	0	17	0
Clouds	0	0	0	0	0	3
Sum	35	15	56	3	17	3
Accuracy						
Producer	1	1	1	1	1	1

User	1	1	1	1	1	1
Hellden	1	1	1	1	1	1
Short	1	1	1	1	1	1
Overall accuracy						
KIA* Per Class	1	1	1	1	1	1
Totals						
Overall Accuracy	1					
KIA*	1					

**Kappa Index of Agreement*

Table 11: Error matrix based on samples

3.8.5 Dealing with vegetation related items

The importance of vegetation indexes as a malaria predictive factor was discussed in Chapter 1. According to the spatial extent of vegetation within the administrative boundaries of Yaoundé (37% of the total surface), it can empirically been presumed that vegetation is playing an important role in the malaria-transmission process. Vegetation features were discriminated during the classification process of QuickBird images (see Chapter 3.9).

3.8.5.1 High spatial resolution Remotely-sensed data

Normalized Differenced Vegetation Index (NDVI) values were calculated from two scenes of ASTER. One was corresponding to the rainy season (November 2007), the other one to the dry season (February 2009). Each of the scenes was first orthorectified using field GPS-data. NDVI values were calculated for each scene using the following formula:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{21}$$

where *NIR* and *RED* stand for the spectral reflectance measurements acquired in the red and near infrared regions.

Each of the scenes was then distributed into classes separating favourable NDVI thresholds to non-favourable (see tab. 12). It is assumed that the NDVI must reach a certain value in order to be able to indicate the presence of potential mosquitoes breeding sites (OMUMBO et al., 1998).

Categories	Favour or not breeding sites presence	Threshold values for the dry season	Treshold values for the rainy season
Cat 1	Unfavorable	-1 to -0.5	-1 to -0.5
Cat 2	Unfavorable	-0.51 to 0.28	-0.51 to 0
Cat 3	Unfavorable	0.29 to 0.47	0.1 to 0.5
Cat 4	Favourable		0.51 to 1

Table 12: NDVI favourable and unfavourable thresholds values

3.8.5.2 Extraction of Urban Agriculture (UA) zones

The importance of urban agriculture (UA) to malaria was discussed in Chapter 1. UA is intensively practised in Yaoundé (ZEMTSOP, 1998; NJOM, 1999; ENDAMANA, 2000; TEMPLE, 2002; BOPDA, 2003). In fact, ecological conditions such as a dense drainage network, favourable soils, added to economic conditions such as unemployment drive an important part of the population into agricultural activities. In a pure ecological perspective, what is interesting in this study is the practice of UA not only for domestic (spatially reduced) needs but mainly for commercial purposes (spatially extended) (ENDAMANA, 2000).

In an ecosystem such as Yaoundé, characterized by a high presence of natural vegetation (sometimes relics of equatorial forest), agricultural patterns are difficult to extract automatically from optical remotely sensed data without a probable large part of error due to the spectral confusion between natural vegetation and agricultural zones. Even the geometrical shapes of agricultural zones are not distinguishable enough. For all these reasons a visual process rather than an automated classification was used to extract agricultural areas of Yaoundé.

An important feature of UA in Yaoundé is the proximity of water drainage surfaces to agricultural patterns. In fact, urban farmers are taking advantage of the presence of free sources of water to develop their activity. The drainage system is therefore a good indicator of the presence of extended urban agricultural zones. It was used as such together with the hypothetical drainage system obtained from topographical data. The pansharpened image of QuickBird was also used as visual reference to edit agricultural zones. Polygons representing UA zones at the date when the images were taken were finally obtained. It must be noticed that the extended agricultural zones are likely to be permanent zones (ENDAMENA, 2000). This is not the case of domestic agricultural zones spatially reduced to the close surroundings of households.

3.8.6 Elevation and slope as key elements

A 30 m spatial resolution Digital Elevation Model was obtained from ASTER (Advanced Spaceborn Thermal Emission and Reflection Radiometer). This DEM product thoroughly validated by the United States Geological Survey (USGS) was the second version released on May 2006. In this version, larger water bodies can be detected and cloudy areas appears as bright regions rather than dark (see fig. 26). The viewing Geometry of ASTER is suitable for DEM-generation (CHRYSOULAKIS et al., 2004). The NIR system consisting of two telescopes-one nadir looking and the other backward looking is used in DEM-production.

In the domain of DEM data, the ASTER DEM product seems to constitute the best alternative for Africa. In fact, only QuickBird and IKonos products offer a better spatial resolution. But these data are quite expensive. Free downloadable GTOPO-data from USGS/EOS (Earth Observing System) offer a resolution of only 90 m for Africa. Even the reverse engineering approach of extracting DEMs from topographical maps does not give better results (KONSTANTINOS et al., 2004). In addition, updating these data is financially difficult for African countries.

The relationship of malaria with topographical elements was underlined in Chapter 1. From the generated DEM, it was possible to derivate elevation and slopes data for Yaoundé. These operations were done under 3D-Analyst extension of ESRI.

Elevation and slopes values of each household were extracted using the geoprecessors tool of ArcGIS. Those values were then integrated into the central database already containing other ecological, epidemiological, socio-economic and socio-environmental data. Further bivariate analysis under Stata allowed evaluation of the association between topographical and epidemiologic data.

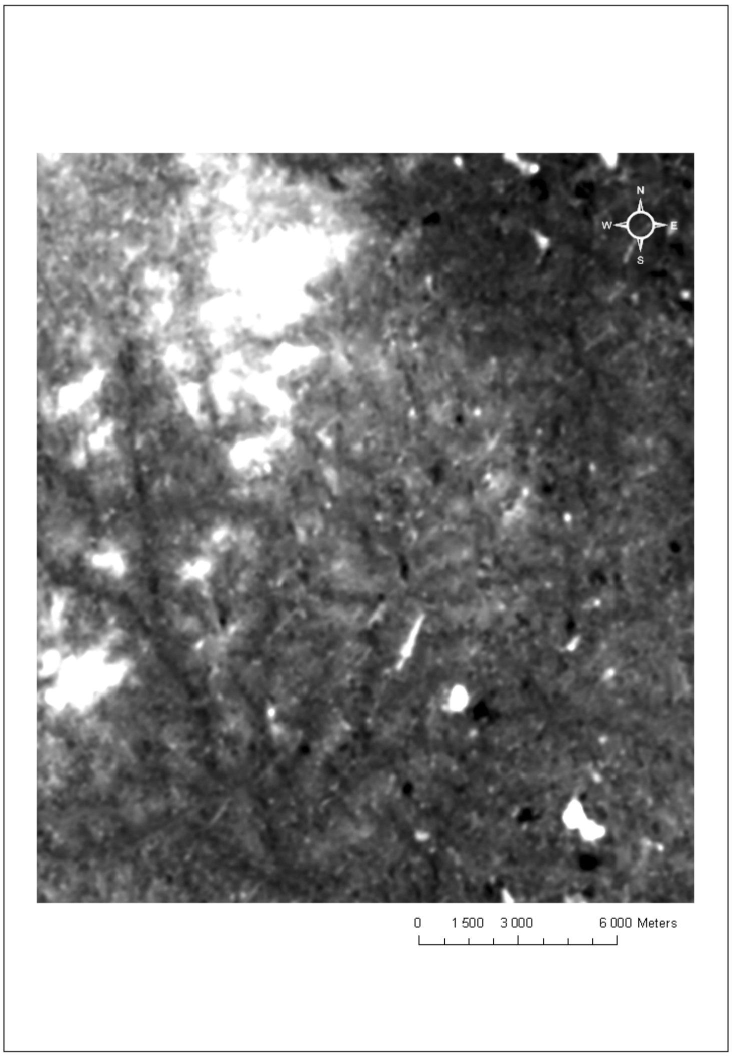


Figure 26: ASTER DEM of Yaoundé

3.9 Identifying the morphological patterns of Yaoundé

By identifying morphological patterns of Yaoundé, the main idea was to translate the social segmentation of the city into its spatial expression. The ultimate objective being to identify the relationship between this spatial segmentation and probable spatial malaria relative risk patterns. The term "social" is seen as ecology; it refers to the sociological concepts of human ecology (BARROWS, 1923; BEWS, 1935; GLAESER, 1989; GROSS, 2004). As previously identified, social patterns were the expression of infrastructural (commodities), economical (incomes) and demographical (population densities) differences, on one hand, and of the difference between rural and urban features on the other hand. This social segregation was expressed as groups/communities differences rather than differences between individuals. In this sense, individuals with the same social profile are shaping the group (VASISHTH & DAVID, 2002). The hypothesis is that, in return, the ecological (in the sense of human ecology) expression of the group/community will influence its exposition to malaria risk. Thus, this malaria risk is spatially expressed as a community/group risk.

3.9.1 A spatial translation of social patterns

In order to evaluate this spatial community-based approach, a map with various population aggregates (PA), representing socio-ecological differences was created. One of the hypotheses supporting this process is that population/households differences in densities of given areas express the socio-ecological differences between these areas. These population/households densities also contribute to the ecological spatial clustering of these areas. Another hypothesis directly related to malaria risk is that the level of isolation of a household will determine its level of exposition to malaria. The higher the urban densities the lesser the malaria prevalence (CHINERY, 1984; PROTHERO, 1989; FONDJO et al., 1992; MARTENS & HALL, 2000; EUBANK et al., 2004). This level of isolation will vary from a population aggregate (PA) / community to another; this variation is attributed to identified differences in local morpho-physical patterns. The key morpho-physical pattern will be the sparsely or non-sparsely distributed household which determines the proximity of one household to another. The distance between households will be an important indicator of the social standing of a household.

In order to make a spatial segregation between spatially dense, less dense (intermediate) and isolated houses/buildings, an aggregation of buildings was performed using a majority filter algorithm with a 3x3 kernel window. The aggregation is made between contiguous pixels while the segregation is made between the resulting dense and less dense groups of PA. One of the criteria of the majority filter is that the majority of cells must have the same value. Another one is that they must be contiguous. The 3x3 kernel window means that the kernel of the filter will be the eight nearest neighbours. Five out of eight connected cells must have the same value.

The formerly obtained QuickBird LULC layer (see Chapter 3.8.4) was introduced into ArcGIS as an input and the majority filter was run. The expectation was that areas of same pixel value expanded in zones where they were in majority at the expense of less represented pixels. Thus areas where vegetation was dominant expanded on other areas types while areas where the buildings were dominant expanded on all the other types. By doing so, densely built-up areas were identified. They clearly form aggregates distinct of less dense areas. However, it was also useful not to completely obliterate isolated households. For this reason and before validating the final maps of PA, visual and statistical tests were performed.

These tests were based on surveys representing three distinct socio-ecological/morpho-structural patterns. Distinct polygons were created, one inside a densely populated area situated in the centre of the city; another one in a peripheral zone with rural patterns characterized by a high presence of vegetation, lack of infrastructures and isolated buildings; and a last one in a high standing zone with less isolated buildings. These spatial surveys were also representative of the ecological dislocation between rural and urban patterns. It was possible to extract the objects “houses roofs” from both the LULC and the new PA layers. The spatial extraction of the results was limited to the polygons previously created (those representing the three test zones). The extractions processes naturally produced three separated layers. At the end of this process, three spatial samples, X_1, X_2 and X_3, representative of the city’s local socio-ecological/morpho-structural patterns where obtained (see fig. 27).

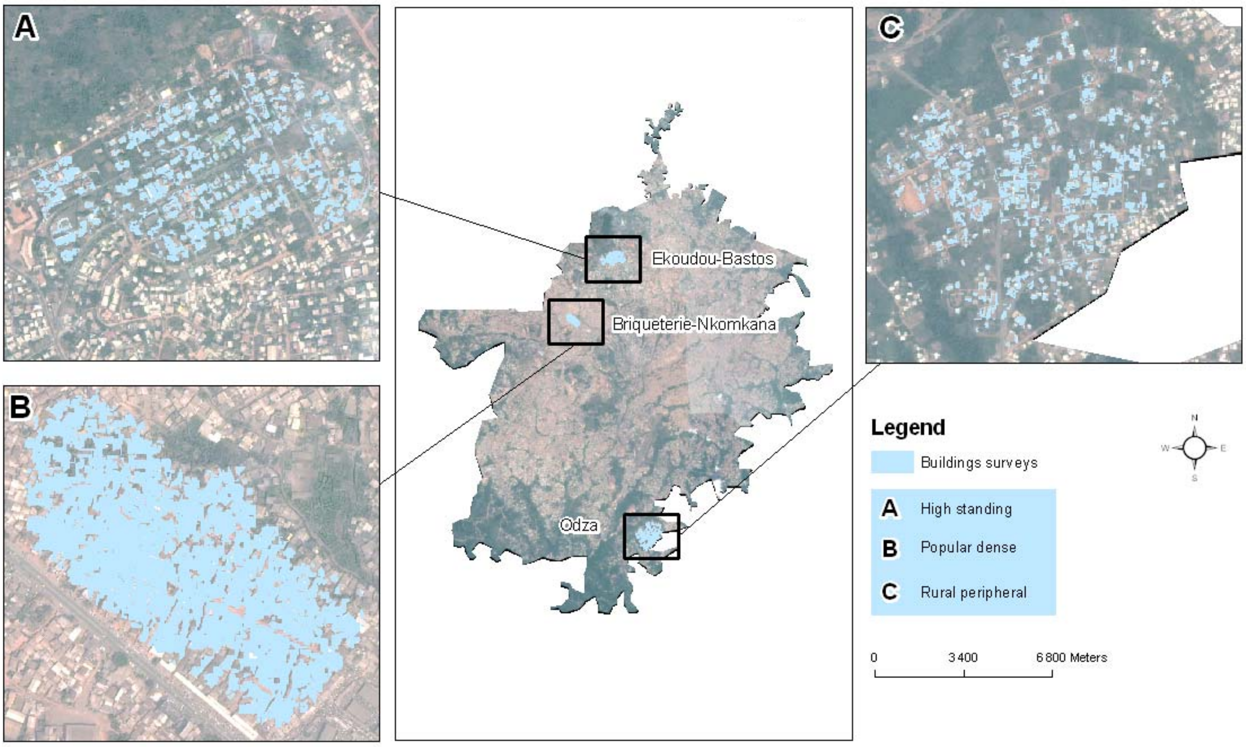


Figure 27: Test of aggregations of population with surveys of various socio-ecological zones

3.9.2 Demographical patterns from remotely-sensed data

With respect to the postulate describing social morphostructures of the city, using population densities as indicating factors, an evaluation of population sizes and densities in various types of PA was made. The first step consisted on estimating the mean total population in a household and the mean surface of a household. The first indicator was calculated using the data from interviews. The mean total number of people $\overline{n_{HP}}$ of a household was calculated simply by dividing the sum of total numbers of people ($\sum_{1}^{n} n_{HP}$) permanently living in each household by the total number of households NH (22):

$$\overline{n_{HP}} = \frac{\sum_{1}^{n} n_{HP}}{NH} \tag{22}$$

The calculation of the mean surface $\overline{S_B}$ of a household followed a more complex process. The newly extracted "buildings roofs" layers of the three test zones were used as representative samples of various socio-ecological/morpho-structural patterns X_1, X_2 and X_3 (see Chapter 3.9.1). Surface area of each object was calculated using ArcGIS. The mean surface $\overline{S_B}$ of a household in each layer was then estimated using the formula described below (23):
The mean surface $\overline{S_{Bi}}$ of sample X_i is equal to the sum of the of building's roofs surfaces $\sum_{1}^{n} S_{Bi}$ of sample X_i, divided by the total number of objects /Building's roofs N_{Bi} ,

$$\overline{S_{Bi}} = \frac{\sum_{1}^{n} S_{Bi}}{N_{Bi}} \tag{23}$$

Once the mean surfaces $\overline{S_{B1}}$, $\overline{S_{B2}}$ and $\overline{S_{B3}}$ of a building's roof in respective samples X_1, X_2 and X_3 were calculated, it was possible to estimate the mean surface $\overline{S_{B,\,Yaoundé}}$ of a building roof in the entire city. $\overline{S_{B,\,Yaoundé}}$ was calculated by summing the mean building's roof surfaces $\overline{S_{B1}}$, $\overline{S_{B2}}$ and $\overline{S_{B3}}$ and dividing it by the sum of the total number objects/building's roofs of each sample X_1, X_2 and X_3:

$$\overline{S_{B,\,Yaoundé}} = \frac{\overline{S_{B1}} + \overline{S_{B2}} + \overline{S_{B3}}}{N_{B1} + N_{B2} + N_{B3}} \tag{24}$$

Samples X_1, X_2 and X_3 were considered instead of the objects/building's roofs of the entire city because it was possible to clean these samples of artefacts due to misclassifications. In other words, each sample X_1, X_2 and X_3 was visually compared to the pansharpened image and misclassifications edited and corrected under ArcGIS. However, another calculation of the total mean surface $\overline{S_B}'_{,\,Yaoundé}$ was made using an extracted layer of building's roofs covering the entire city; the difference was only 6 m^2.

Once the mean surface $\overline{S_B}'_{,\,Yaoundé}$ of a household was calculated, it was possible to estimate the number of households of various segmented PA, $X_1', X_2', \ldots X_n'$. The segmentation process of PA, $X_1, X_2, \ldots X_n$, resulting from the application of the Majority filter algorithm (see chapter 3.9) into new $X_1', X_2', \ldots X_n'$ PA was guided by the need to control the level of isolation of a household. Said in other words, the configuration of the PA $X_1, X_2, \ldots X_n$ obtained by applying the majority filter algorithm was not finite enough to allow analysis based on the degree of isolation of a household. Although the information on the number of houses was implicitly present in raw aggregate, $X_1, X_2, \ldots X_n$, it did not allow proper analysis. The segmentation into more intelligible PA $X_1', X_2', \ldots X_n'$ was made empirically. It consisted of a manual classification of raw PA. Classes' intervals were corresponding to various number of building's roofs, $N_{BX'1}, N_{BX'2}, \ldots N_{BX'n}$. Number of building's roofs, $N_{BX'1}, N_{BX'2}, \ldots N_{BX'n}$, were corresponding to the total surface $S_{X'1}, S_{X'2}, \ldots S_{X'n}$ of a class/PA $X_1', X_2', \ldots X_n'$ divided by the mean surface of a building $\overline{S_{B,\,Yaoundé}}$:

$$N_{BX'i} = \frac{S_{X'i}}{\overline{S_{B,\,Yaoundé}}} \tag{25}$$

Before creating the definitive classes/ PA $X_1', X_2', \ldots X_n'$, a new field was added in the table containing the raw PA $X_1, X_2, \ldots X_n$. This new field was containing information about the estimated number of households in each PA $X_1, X_2, \ldots X_n$, calculated using the previously provided formula (25). This information allowed a statistical estimation of the number of raw PA/classes respectively containing 1, 2, 3, … n building's roofs/houses. Thus it was possible to know if PA with few number of building's roofs/houses were more frequent than those with a big number of households (densely populated). This evaluation helped in making a manual classification of population aggregates (PA).

The total population $P_{,\,Yaoundé}$ of the city was estimated using the mean surface of a household $\overline{S_{B,\,Yaoundé}}$, the mean total population in a household $\overline{n_{HP}}$ and the extracted "building's roofs" class objects. Surface area of each "Building's roofs" object was calculated. Population estimates of each object/polygon $P_{BX1}, P_{BX2}, \ldots P_{BXn}$ were estimated by dividing each class object's surface, $S_{BX1}, S_{BX2}, \ldots S_{BXn}$ by $\overline{S}_{B,\,Yaoundé}$ and multiplying the result by the mean total population in a household $\overline{n}_{HP}$ The total population estimate $P,_{Yaoundé}$ was obtained by summing the population estimates of all the class objects (26):

$$P,_{Yaoundé} = P_{BX1} + P_{BX2} + , \ldots P_{BXn} \tag{26}$$

The population densities of the districts $DS,_{districts}$ were estimated by using the population of each object/polygon $P_{BX1}, P_{BX2}, \ldots P_{BXn}$ from the extracted "Building's roofs" class objects and the surfaces of the districts layer $S,_{districts}$. The population density in a district $DS,_{district}$ was estimated by dividing the total population $P,_{district}$ of this district by its surface $S,_{district}$ (27):

$$DS,_{district} = \frac{P,_{district}}{S,_{district}} \tag{27}$$

3.9.3 Calculating an Index of Urbanity (IU)

The reasons leading to the calculation of an index of urbanity IU can be found in the continuity of the hypothesis stipulating the existence of a correlation between ecological patterns and that of malaria-transmission risks. Medical entomological studies have demonstrated that the variation of the presence of malaria's vectors types and their action on the human were dependent on the variations of ecological status of the *niches* (see Chapters 2.2 and 2.5.3..1). The expansion of the city is a key indicator of the variation of the ecological status of these *niches*. As said previously this expansion is made at the expenses of natural ecosystems mainly composed of vegetation (healthy forested, stressed vegetation). An IU will indicate both the actual geographical orientation of the city's expansion and the degree to which urban factors such as buildings (houses and services) and paved roads (high level of communication network) have colonized rural settings.

A map of IU was obtained from the LULC-classification of QuickBird. During the conception of the IU, a clear difference was made between features considered as belonging to urban patterns, and features considered as belonging to rural patterns. Features belonging to both rural and urban settings were also considered. Vegetation was finally integrated as the only key rural feature. In fact, features such as water bodies or bare soils were not good discriminators, simply because they can be found both in rural (peri-urban very sparse building distribution) and very urban (denser building's distribution) parts of the city. Buildings' roofs and paved roads were considered as being good urban discriminators. In fact, only roads having a national status are paved in the rural settings. There exists only one national road, joining Yaoundé to Douala in the direction to the south. The presence of buildings was considered as the basic fundamental expression of the potential of urban settlement and expansion. Buildings were the most present feature after the vegetation; they were then the features that were physically and spatially making a clear transition with the vegetation (rural settings). For these reasons, buildings were chosen as the basic key element in the calculation of the IU.

The mean surface $\overline{S}_{B1}$ of a building in a densely populated area was taken as the base for calculating cells dimensions C_{gi} of the spatial grids integrated in the calculation of the IU. Cells dimensions C_{gi} were obtained by dividing $\overline{S}_{Bi}$ by 4 (28):

$$C_{gi} = \frac{\overline{S_{B1}}}{4} \tag{28}$$

$\overline{S_{B1}}$ was more representative of the urban settings than $\overline{S_{B2}}$ and $\overline{S_{B3}}$. $\overline{S_{B1}}$ therefore constituted an additional discriminator between rural and urban settings. The first step consisted of the transformation of the LULC layer into a regular gridded raster layer corresponding to the dimensions of C_{gi}. This new gridded LULC raster was then converted into a vector layer with polygons dimensions exactly corresponding to a square with $\overline{S_{B1}}$ dimensions. The total Surface area of each of the polygons S_{TPi} was then calculated into a new field. Surface areas of each object feature were also calculated: vegetation surface S_{Vi}, water bodies surfaces S_{Wi}, bare soil surfaces S_{BSi}, paved areas surfaces S_{Pi}, building's roofs S_{Bi} surfaces. The calculation of the final IU of a polygon was based on the following formula (29):

$$IU_i = \frac{\left(\left(S_{TPi}\right) - \left(S_{Wi} + S_{BSi}\right)\right) - \left(S_{Bi} + S_{Pi}\right)}{\left(S_{TPi}\right) - \left(S_{Wi} + S_{BSi}\right)} \tag{29}$$

3.10 Multinomial regressions models based on thematically distinct predictive factors

After selecting and creating all the variables, the next step consisted of evaluating the effects of these variables on the MRR. This evaluation had a statistical and a spatial component. The statistical evaluation followed a stepwise approach: the objective was to reduce the complexity of the final statistical models by selecting predictive variables on the basis of the significance of their statistical correlation with MRR. A parallel selection was made using an empirical-statistical selection process based on the close thematical relationship between predictive variables.

3.10.1 Bivariate analyses for a meticulous selection of variables associated with the Malaria Relative Risk

Prior to the bivariate analysis, some operations aiming to obtain a table with observations (households) having all the requested variables (items) in an appropriated format were performed. It should be noted that the selected variables had different spatial formats. Some were already in the adequate format, namely as points corresponding to households. This was the case of geoepidemiological and geosocial variables (variables collected during the interviews). Most of the ecological variables still had a pixel-based spatial structure. It was therefore necessary to integrate these variables into the formal definitive structure by extracting their values to points (households).

The Households Distance to Feature Method (HDFM) is a neologism, an acronym created to represent a complex process of data transformation. The basic idea is to consider households' distances to the ecological variables, rather than considering the *in situ* (at the exact longitudinal and latitudinal position) values of the households/points. The logic of distance calculation is related with the potential presence of breeding sites as well as the fly capacities of *Anopheles* (GITHEKO et al., 1996; KAUFMANN & BRIEGEL, 2004). It is assumed that natural ecological features produce favourable breeding sites to *Anopheles*. The adult *Anopheles* will fly in order to find a host. The probability to find a host is related with the presence of vertebrate (mostly human in the urban context). Thus, the hypothesis is that the level of exposition of a vertebrate (in a household) will depend on the distance of its household to the

potential breeding site (see fig. 28). Therefore, it makes more sense to consider this distance rather than the corresponding *in situ* households' value of natural ecological variables.
The first step in the HDFM process is to transform all polygons layers into polylines layers. An empty polyline coverage is created, and then concerned features are copied and pasted into this new empty coverage using editing options of ArcGIS. The result is a polyline feature representing the borders of each former polygon. There was no need to transform features that were already polylines, they were simply copied and pasted into the empty polylines features. This was the case with some of the hydrological layers (see chapter 3.8.3). Since there were a polyline and a polygon layer, they were merged together into a single polyline layer.

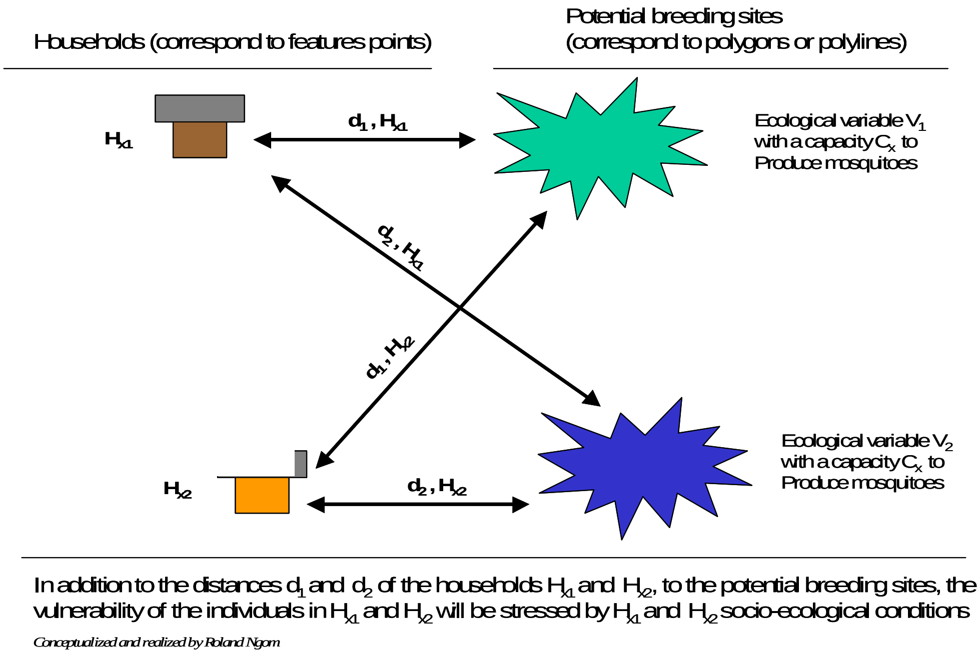


Figure 28: Snapshot description of households' vulnerability according to breeding sites distances and *in situ* socio-ecological variables.

The second step consisted on the transformation of the new polylines features into points. This was imposed by the prerequisites of the algorithm used to calculate the final distances. In fact, Hawth's tool modules were added to ArcGIS in order to perform the final distance calculation. The point-to-point distance calculation of Hawth's tool requires two feature points layers. Once the new polylines layers (from various ecological variables) were transformed into points, it was possible to introduce it together with the household layer in the Hawth's tool distance calculation module. Nearest distances of households to the feature points representing ecological variables were calculated (see fig. 29). At the end step, exact distances of households to the nearest ecological features were obtained.

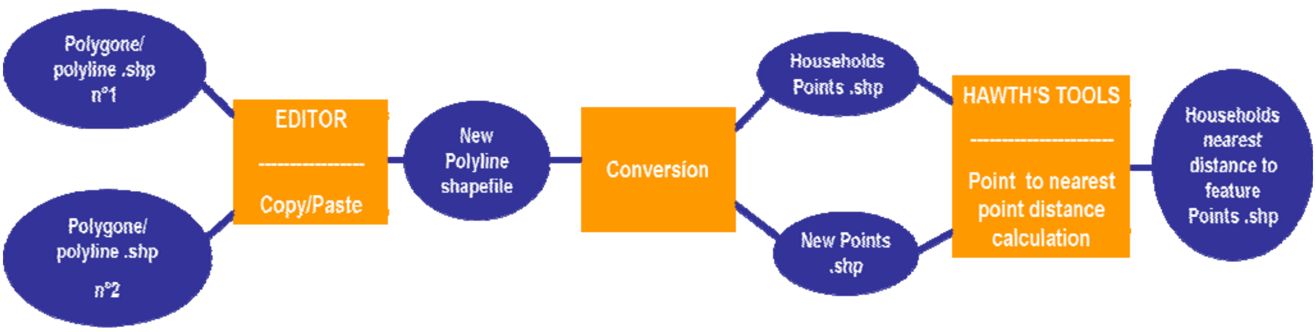


Figure 29: The Households Distance to Feature Method (HDFM) analyses description

The ecological variables that were subject to this processing method are listed in table 13. All the other ecological variables were submitted to a simple extraction process. That means that the households' values of these variables were extracted *in situ*. This was done with the help of the extract-to-point module of ArcGIS.

Variables
NDVI rainy season category 1
NDVI rainy season category 2
NDVI rainy season category 3
NDVI rainy season category 4
NDVI dry season category 1
NDVI dry season category 2
NDVI dry season category 3
NDVI dry season category 4
Vegetation
Water bodies
Bare soils

Table 13: List of variables submitted to the Household Distance to Feature Method (HDFM)

Malaria Relative Risk (MRR) values were separated into four classes corresponding to gradual values: 0 for no malaria, 1 for malaria low, 2 for malaria middle, and 3 for malaria high. In order to deal with binary variables, the malaria odds risks variable was also transformed into a binary variable, with the value 0 for no malaria and 1 for malaria present. Different bivariate analyses were performed under Stata, depending on the nature of the independent variables (see tab. 14). This step allowed the exclusion of variables that were not significantly correlated with MRR.

This statistical-based exclusion procedure was followed by a thematically based one. It consisted of the exclusion of formerly selected variables thematically closed. For example, if the Economic Capacity (EC) of a household and the professional occupation of the head of this household were all significantly correlated to MRR, it was logically deduced that the variable EC was influenced by the variable occupation of the head of the household. It therefore made sense to maintain the hypothesis that the two of these variables were thematically highly similar. This last hypothesis was tested by another statistical bivariate analysis between the two variables. When the correlation was significant, several positions were considered. The predictive variable that was thematically closed to several other predictive variables was preferred, because it constituted a good proxy to these variables. In the case of the presence of only two thematically close predictive variables, the variable with the highest correlation value with MRR was preferred. These operations were important steps in the process of simplification of the statistical models.

N°	Items	Binary MRR	Ordinal MRR
	Socio-ecologic		
1	Room crowding coefficient		Spearman correlation test
2	Wall quality coefficient		Spearman correlation test
3	Wall made with fortified soil bricks	Simple logistic regression	
4	Wall made with cement bricks	Simple logistic regression	
5	Wall made with “poto poto”	Simple logistic regression	
6	Wall made with wood or aluminium or mixture of unstable materials	Simple logistic regression	
7	Roof quality coefficient		Spearman correlation test
8	Roofs made of tiles or cements (cover labs)	Simple logistic regression	
9	Roofs made of aluminium	Simple logistic regression	
10	Roofs made with other types of material	Simple logistic regression	
11	Building with multiple floors	Simple logistic regression	

12	Household crowding coefficient		Spearman correlation test
13	Prevention behavior coefficient		Spearman correlation test
14	Presence/absence of vegetation	Simple logistic regression	
15	Presence/absence of rivulets around the house	Simple logistic regression	
16	Presence /absence of well around the House	Simple logistic regression	
17	High standing Housing	Simple logistic regression	
18	Intermediate standing Housing	Simple logistic regression	
19	Poor standing Housing	Simple logistic regression	
20	Permanent presence of animals around the house	Simple logistic regression	
21	Evident gaps on walls	Simple logistic regression	
22	Presence/absence of roof ceiling	Simple logistic regression	
23	External/internal toilets	Simple logistic regression	
24	Opened windows	Simple logistic regression	
25	Opened doors	Simple logistic regression	
Prevention			
26	Coefficient of mosquito net utilization		Spearman correlation test
27	Number of persons sleeping under a non-treated mosquito net		Spearman correlation test
28	Number of persons sleeping under a treated mosquito net		Spearman correlation test
29	Usage of insecticides	Simple logistic regression	
30	Regular cleaning of surroundings	Simple logistic regression	
31	Grids on windows	Simple logistic regression	
32	Preventive drugs utilization frequency		Spearman correlation test
33	EIG coefficient		Spearman correlation test
34	Level of malaria-knowledge		Spearman correlation test
	Socio-economic		
35	Economic capacity coefficient		Spearman correlation test
36	Informal sector as major professional Activity	Simple logistic regression	
37	Declared commercial activity	Simple logistic regression	
38	Civil servant	Simple logistic regression	
39	Agricultural activities	Simple logistic regression	
40	No studies	Simple logistic regression	
41	Primary level of study	Simple logistic regression	
42	Secondary level of study	Simple logistic regression	
	Ecologic		
43	Elevation		Spearman correlation test
44	Slopes		Spearman correlation test
45	Distance to vegetation		Spearman correlation test
46	Distance to bare soil		Spearman correlation test
47	Distance to water bodies		Spearman correlation test
48	Distance to NDVI category 1		Spearman correlation test
49	Distance to NDVI category 2		Spearman correlation test
50	Distance to NDVI category 3		Spearman correlation test
51	Distance to NDVI category 4		Spearman correlation test
52	IU		Spearman correlation test
53	Very Isolated PA	Simple logistic regression	
54	Isolated PA	Simple logistic regression	
55	Intermediate I PA	Simple logistic regression	
56	Intermediate II PA	Simple logistic regression	
57	Very dense PA	Simple logistic regression	
58	Extremely dense PA	Simple logistic regression	

Table 14: List of malaria potential predictive variables with types of correlation applied

3.10.2 Multinomial logistic regressions models with spatial applications

After identifying the most significant predictive variables, the next step of the analysis dealt with the evaluation of the contribution of the selected variables to the malaria risks using a multinomial modelling method. Multinomial analysis allowed integration of various data types (categorical, non-categorical) as predictors into the regression equation (LONG, 1997). The variables finally selected are listed in the table 15. Variables were separated into thematically distinct groups. An evaluation of the contribution of each group of variables (socio-economic, socio-ecological, ecological, preventive behaviour) on malaria risk was made. Since the number of weather stations was spatially inconsistent, climate variables were not included into the ecological model.

Variables	Origin	Remarks
Ecological variables		
Elevation	ASTER	
Distance to agricultural features	Quickbird	
Socio-ecological variables		
Room crowding coefficient	Field interviews	
External toilets	Field interviews	
Isolated household	Field interviews	
Socio-economic variables		
Economic capacity	Field interviews	
Antimalarial behavioral variables		
Number of persons under mosquito bed nets per household	Field interviews	
Coefficient related with utilization of insecticides, regular cleaning of surroundings and presence of grids on windows.	Field interviews	Mathematical variables that only include surrounding cleaning, utilization of grids on windows and utilization of insecticides (see the equation (18))

Table 15: Variables included in the multinomial logistic regression (Mlogits) models

Mlogits (Multinomial logistic regression) models of each of the variables categories/groups (socio-economic, socio-ecological, ecological and behavioural) were performed at 95% confidence intervals. They used the Malaria relative Risk (MRR) as a categorical outcome that identifies no, low, middle and high malaria presence. The classical multinomial logistic regression equation (30) was used for each model.

$$\log\left(\frac{\Pr Y}{1-\Pr Y}\right) = \beta o + \beta_1 X_1 + \beta_2 X_2 + \ldots \beta_i X_i \tag{30}$$

where $\log\left(\frac{\Pr Y}{1-\Pr Y}\right)$ is the natural logarithm of the ratio of the probability of the occurrence of Y and the probability of the non-occurrence of Y. In the present case Y takes four forms: no malaria, low malaria, middle malaria and high malaria presence. Each of these levels has its own equation line.

βo is a constant calculated for each equation line.

$\beta_1 \ldots \beta_i$ are the coefficients of the regressions models; $X_1 \ldots X_i$ are the independent variables.

For a better understanding of the applied model the following equations (31), (32) and (33) are formulated for the socio-ecological model:

$$\log\left(\frac{\Pr \mathrm{K}_0}{\Pr \mathrm{K}_3}\right) = \beta o, \mathrm{K}_0 + \beta_{X_1,\mathrm{K}_0} * X_1 + \beta_{X_2,\mathrm{K}_0} * X_2 + \beta_{X_3,\mathrm{K}_0} * X_3 \tag{31}$$

$$\log\left(\frac{\Pr K_1}{\Pr K_3}\right) = \beta o, K_0 + \beta_{X_1,K_1} * X_1 + \beta_{X_2,K_1} * X_2 + \beta_{X_3,K_1} * X_3 \quad (32)$$

$$\log\left(\frac{\Pr K_2}{\Pr K_3}\right) = \beta o, K_2 + \beta_{X_1,K_2} * X_1 + \beta_{X_2,K_2} * X_2 + \beta_{X_3,K_2} * X_3 \quad (33)$$

where: K_0 identifies malaria absence category;

K_1 identifies malaria low category;

K_2 identifies malaria middle category; K_3 identifies high malaria presence category.

K_3 is used as the reference category in the equation its coefficients are equal to 0; X_1, X_2 and X_3 are the independent variables used to build-up the socio-ecological model, they are: room crowding coefficient, external toilets and isolated households (see tab. 16); β_{X_1}, β_{X_2} and β_{X_3} are the coefficients obtained for each variable after the regression: the higher the coefficient the higher the contribution of the variable to the model. These coefficients also indicate if the relationship to malaria odds is positive or negative.

As result of this process, each observation was granted with four new values that were the coefficients (C_0, C_1, C_2 and C_3) for each category (K_0, K_1, K_2 and K_3). These values were transformed into probabilities applying the following formulae (34), (35), (36) and (37) under Stata:

$$\Pr(K_0) = \frac{e^{\log(odds),K_0}}{1 + e^{\log(odds),K_0} + e^{\log(odds),K_1} + e^{\log(odds),K_2} + e^{\log(odds),K_3}} \quad (34)$$

$$\Pr(K_1) = \frac{e^{\log(odds),K_1}}{1 + e^{\log(odds),K_0} + e^{\log(odds),K_1} + e^{\log(odds),K_2} + e^{\log(odds),K_3}} \quad (35)$$

$$\Pr(K_2) = \frac{e^{\log(odds),K_2}}{1 + e^{\log(odds),K_0} + e^{\log(odds),K_1} + e^{\log(odds),K_2} + e^{\log(odds),K_3}} \quad (36)$$

$$\Pr(K_3) = \frac{e^{\log(odds),K_3}}{1 + e^{\log(odds),K_0} + e^{\log(odds),K_1} + e^{\log(odds),K_2} + e^{\log(odds),K_3}} \quad (37)$$

Where $e^{\log(odds)}$ is the exponential logarithm of the relative risk previously calculated: $\log\left(\frac{\Pr Y}{1 - \Pr Y}\right)$

The end allocation of probabilities was made applying the following steps under Stata:

- Creation of new empty variables: Pr_0, Pr_1, Pr_2, and Pr_3 for each category K_0, K_1, K_2 and K_3
- Allocation of correct predictions based on coefficients C_0, C_1, C_2 and C_3 to each category with the following code (frame (a)):

(a)

→ `replace Pr0=1 if` $C_0 > C_1$ & $C_0 > C_2$ & $C_0 > C_3$ *(put all the coefficients values of C_0 in the new variable Pr_0 if they are higher for the category K_0 than for the others);*

→ `replace Pr1=1 if` $C_1 > C_0$ & $C_1 > C_2$ & $C_1 > C_3$ *(put all the coefficients values of C_1 in the new variable Pr_1 if they are higher for the category K_1 than for the others);*

→ `replace Pr2=1 if` $C_2 > C_0 \& C_1 > C_1 \& C_2 > C_3$ *(put all the coefficients values of* C_2 *in the new variable Pr2= if they are higher for the category* K_2 *than for the others);*

→ `replace Pr3=1 if` $C_3 > C_0 \& C_3 > C_1 \& C_3 > C_2$ *(put all the coefficients values of* C_3 *in the new variable Pr3 if they are higher for the category* K_3 *than for the others);*

- Assembling Pr_0, Pr_1, Pr_2 and Pr_3 in a new variable named prediction with the following code (frame (b)):

(b)

→ `Gen prediction=0 if Pr0==1` *(corresponds to the malaria absent good predictions)*
→ `replace prediction=1 if Pr1==1`*(corresponds to the malaria low good predictions)*
→ `replace prediction=2 if Pr2==1`*(corresponds to the malaria middle good predictions)*
→ `replace prediction=3 if Pr3==1`*(corresponds to the malaria high good predictions)*

The variable Pr named "prediction" contained the final values of the predictions of each model with an interval ranging between 0 and 3, corresponding to the four categories previously described (no, low, middle and high malaria presence). With this last variable it was possible to evaluate the quality of the prediction. Using relational database queries under Access, it was possible to count the number of good predictions. The SQL-method used was simply based on a selection of observations/households where the values (0, 1, 2 or 3) of observed and predicted malaria of a category were similar. It was then possible to count the number of correctly predicted observations/households to that of observed malaria odds of the same category, and derive a correct prediction rate.The following formula (38) corresponds to the calculation of the percentage of the correct prediction of the "no malaria" category:

$$r_{CPK_0} = \left(\frac{\sum_{0}^{1019} CPK_0}{N_{OK_0}} \right) * 100 \tag{38}$$

where $rCPK_0$ is the correct prediction rate of "no malaria's category of any of the models; CPK_0 is the number of "no malaria" observations/households where malaria was correctly predicted.

N_{OK_0} is the number of observed "no malaria" observations/households.

The following formulas will respectively correspond to the calculation of the correct prediction rates of the categories low, middle and high:

$$r_{CPK_1} = \left(\frac{\sum_{0}^{148} CPK_1}{N_{OK_1}} \right) * 100 \tag{39}$$

$$r_{CPK_2} = \left(\frac{\sum_{0}^{85} CPK_2}{N_{OK_2}} \right) * 100 \tag{40}$$

$$r_{CPK_3} = \left(\frac{\sum_{0}^{156} CPK_3}{N_{OK_3}} \right) * 100 \tag{41}$$

The total percentage r_{mpp} of malaria's presence correct prediction is an addition of the number of observations of the categories low, middle and high that were correctly predicted divided by the addition of the number of observed malaria belonging to the same categories (42):

$$r_{mpp} = \left(\frac{\sum_{0}^{148} CPK_1 + \sum_{0}^{85} CPK_2 + \sum_{0}^{156} CPK_3}{N_{OK_1} + N_{OK_2} + N_{OK_3}} \right) * 100 \quad (42)$$

It was possible to calculate predicted malaria prevalence P_{mP}. The calculation of this prevalence only uses correctly predicted values (43):

$$P_{mP} = \left(\frac{\sum_{0}^{148} CPK_1 + \sum_{0}^{85} CPK_2 + \sum_{0}^{156} CPK_3}{\sum_{0}^{1019} CPK_0 + \sum_{0}^{148} CPK_1 + \sum_{0}^{85} CPK_2 + \sum_{0}^{156} CPK_3} \right) * 100 \quad (43)$$

Where the numerator represents the sums of the number of observations/households contained in the variable prediction, where malaria presence for the categories (low, middle, high) were correctly predicted;
the denominator is the total number of observations contained in the variable prediction, where malaria presence for all the categories (absent, low, middle, high) were correctly predicted.

In order to evaluate the predictive values of all the models, a new variable $\Pr_T$ was created. $\Pr_T$ was computed using SQL-queries under Access. $\Pr_T$ values were 0 for no malaria and 1 for malaria presence. An observation/household took the value 1 (malaria presence) if any of the values of the variables Pr prediction of any of the models was superior to 0. If all of the values of the variables Pr prediction of all of the models were equal to 0, $\Pr_T$ was attributed the value 0 (no malaria):

$\Pr_T = 1$ if $\Pr$, ecological model OR $\Pr$, socio-ecological model OR $\Pr$, socio-economic model OR $\Pr$, socio-behavioural model > 0

$\Pr_T = 0$ if $\Pr$, ecological model OR $\Pr$, socio-ecological model OR $\Pr$, socio-economic model OR $\Pr$, socio-behavioural model $= 0$

This method allowed optimisation in the identification of malaria presence. It was possible to compare the results of $\Pr_T$ with observed malaria.

The geographic information attached with each household/observation allowed the building of predictive maps. A Radial Basis Function (RBF) method (BURROUGH & MCDONNELL, 1998) was used to compute spatial interpolation of the variables $\Pr_T$ and Pr of the ecological, socio-ecological, socio-economic and behavioural models. Additional hot spots analyses based on the Getis Ord General G index (GETIS & ORD 1992, 1996) led to the identification of high and low malaria zones (clusters). These computations performed under ArcGIS allowed the building of hot spots maps.

3.10.3 Seasonal statistical modelling

Additional bivariate analyses were made on the basis of seasonal variations of the MRR. MRR prevalence was distributed according to the four existing seasons. Rather than making a classical empirical division, thresholds were used. Since the temperatures did not have a significant impact on the variation of the MRR prevalence, seasonal thresholds were based on rainfall values (see tab. 16). These thresholds were not the product of empirical personal observations, they originated from literature relating to the EU-funded project entitled DEMETER (Development of a European Multimodel Ensemble system for seasonal to inter-annual prediction) and the results of the LMM (Liverpool Malaria Model). The MRR seasonal values were finally the products of the aggregation of several MRR monthly values. It implies that during the calculation of seasonal MRR, the mean values within the formulas were recalculated in order to correspond to the selected period (see the formula (4)).

		Rainfall values at the Nsam station	
Months	**Season**	**Minimum value (mm)**	**Maximum value (mm)**
December-February 2006	Big dry season	5.2	32.6
March-June 2006	Small rainy season	147.8	230.6
July-August 2006	Small dry season	25.3	46.7
September-November 2006	Big Rainy season	101.8	259.2

Table 16: Threshold values used to separate seasons

Once the seasonal MRR values were obtained, statistical bivariate analyses with ecological variables were performed. The exclusion of social variables was based on the assumption that they do not change from one season to another within the same selected calendar period. Ecological variables in this sense are more indicative of the seasonal variations. The bivariate analyses were performed under Stata. They followed the same protocol as with non-seasonal MRR.

PA and IU were also correlated to seasonal MRR. The assumption is that variations in the morphological structures have an ecological signification. The very densely populated areas, for example, will not have the same NDVI values as less densely populated areas. These densely populated areas will have a different IU to that of less densely populated areas. All things being equal, the ecological conditions will vary from one morphological structure to another and from a season to another within the same morphological structure.

3.11 A Fuzzy Logic-based spatial simulation of malaria risk

As already evocated in Chapter 3.8.4, the theory of Fuzzy Logic deals with uncertainties. This theory was first raised by the mathematician Lotfih A. Zadeh (ZADEH, 1965). It is a response to the insufficiency of Boolean algebra to many problems of the real world. While Boolean mathematics only recognizes crisp values of "0" and "1", Fuzzy Logic also recognizes the information between "0" and "1". Introducing Fuzzy Logic in spatial analyses and spatial thinking tools (GIS) is a step forward in the simulation of the human thinking (artificial intelligence) into these fields. In fact most of the information in the real world is imprecise, and one of humans' greatest abilities is to effectively process imprecise and “Fuzzy” information.

The complexity of factors intervening into malaria-transmission reflects the difficulty to decide which of the factors is suitable to malaria-transmission. The multinomial approach used above gives key statistical and spatial indications on the suitability of each factor as well as groups of factors to the transmission of malaria. But, like all regression-models there is a remaining uncertainty. This uncertainty is usually expressed by the residuals of the model, meaning it hypothetically represents all the other potential predictive factors not included in the model. But, this uncertainty can also be the result of a process that is basically crisped. In this model, the relationship of each predictive factor with the dependant variable is analysed on the basis of a Boolean suitability. The multinomial regression model is basically treating the relationship between dependent and independent variables as in a normal binary logistic regression. It can be seen as multiple assets of binary logistic regressions at the same time. The probabilities derived from multinomial regressions processes are, in fact, expressed in the direction of one parameter (malaria equal low for example), there is no ambivalence as it would be expressed in the case of Fuzzy Logic.

In the Fuzzy Logic approach, the data are seen as Fuzzy sets with various rules. Rules may contain various logical operators like “AND”, “OR”, “IF” and “WHEN”. They can also contain minimum and maximum values. Thus vagueness, ambiguity and ambivalence are well expressed here (BURROUGH, 1992; OPENSHAW, 1997). Moreover, the particular logic of a question could be expressed through this method. It is, for example, plausible to evaluate the membership of a household to both malaria present and malaria absent at the same time and according to the suitability with various predictive variables.

Another reason justifying the utilization of a Fuzzy Logic approach is found in the derivation of suitable and non-suitable membership values of predictive variables that will be used in an automated prediction process. The idea is to reduce the entry number of predictive variables, while at the same time reducing the heavy logistic system that was necessary to collect the data. Remote Sensing data were seen as a good proxy to the predictive factors.

Remote sensing data are also advantageous because they cover the entire city. There is no need of spatial interpolation. It hypothetically induces a reduction of the spatial prediction uncertainties. The optical nature and the spatial resolution of these remote sensing data will also give the opportunity to distinguish and target only habitated areas.

3.11.1 An urban malaria expert knowledge-base

In order to check whether the spatial morphostructures of the city were describing specific malaria spatial patterns, the feature layers of the population aggregates (PA) and that of the index of urbanity (IU) were confronted to the feature layer of Malaria Relative Risk (MRR). In the case of the comparison with PA, the MRR feature points layer was transformed into polygons layer by using a Radial Basis Function (RBF) interpolation method (Chapter 3.5). An extraction of MRR values to ‘PA’ polygons was made using the extract-to-polygon module of ArcGIS. Mean MRR values of each PA class was then considered and graphically compared.

Another analysis of the relationship of PA with MRR was performed on the basis of the membership of households (from the field survey) to classes of PA. Allocation of membership was made by extracting PA values to points/household. Households were then separated into various items according to the various PA classes. Each of these classes was correlated with MRR using Stata. The comparison of IU to MRR followed exactly the same protocol.

The elaboration of a knowledge-base was a primordial step towards the real Fuzzy-modelling. This knowledge-base was supposed to express the logical relationship between malaria and the morphospatial structure of the city. For this reason analyses aiming to assess the epidemiological and social signification of PA, on one side, and of the IU, on other side, were conducted. Only relevant malaria predictors revealed from the former statistical analyses were considered. Various bivariate analyses were then conducted between these variables and each PA as well as with the IU (see tab. 17). Prior to these analyses, the “urban” (in the sense of the IU) characteristics of each PA was assessed by correlating the IU with each PA (see tab. 17).

Data of IU and PA variables for these analyses were derived from a spatial extraction process. It means that the features, points representing the field households survey, were used to extract values of IU and PA. They were the only variables that were lacking to these observations/households. The relevant predictive factors were already present. PA was represented as a categorical variable distinguishing the morphostructural classes to which was belonging each household/observation.

Items	Binary individual PA	Ordinal PA	IU
Socio-ecologic			
Room crowding coefficient	Spearman correlation test	Spearman correlation test	Pearson correlation test
Household crowding coefficient	Spearman correlation test	Spearman correlation test	Pearson correlation test
External/internal toilets	Simple logistic regression		
Prevention			
Prevention behavior	Spearman Correlation test	Spearman correlation test	Pearson Correlation test
Number of persons sleeping under a non-treated mosquito net	Spearman correlation test	Spearman correlation test	Spearman correlation test
EIG coefficient	Spearman correlation test	Spearman correlation test	Pearson correlation test
Level of malaria-knowledge	Spearman correlation test	Spearman correlation test	Pearson correlation test
Socio-economic			
Economic capacity coefficient	Spearman correlation test	Spearman correlation test	Pearson correlation test
Informal sector as major professional activity	Simple logistic regression		Spearman correlation test
Declared commercial activity	Simple logistic regression		Spearman correlation test
Civil servant	Simple logistic regression		Spearman correlation test
Ecologic			
Elevation	Spearman correlation test	Spearman correlation test	Pearson correlation test
Distance to UA areas	Spearman correlation test	Spearman correlation test	Pearson correlation test
Distance to water bodies	Spearman correlation test	Spearman correlation test	Pearson correlation test
IU	Spearman correlation test	Spearman correlation test	

Table 17: Bivariate analyses between malaria relevant variables and population aggregates (PA) / Index of Urbanity (IU)

In accordance with the results of the former bivariate analyses, it was decided to use the IU and PA as proxy variables that determined the membership to the presence and absence of malaria. The assumption was that the malaria risk was varying according to both the degree of urbanity and the membership to a particular PA (which had a particular epidemiological, social and ecological signification). This malaria risk membership suitability was at the same time considering the significance of PA to the IU. For this, a linear and symmetric membership function was implemented.

Pixels obtained from the IU-map were considered as the basic population (their resolution was corresponding to the mean surface of a building object). The IU-values were then used to define the control points of the membership functions. The MRR variable was used to define the suitability to malaria presence (1) and the suitability to malaria absence (0). Normal confidence intervals of IU, when malaria is suitable (1) and when it is not (0), were calculated. They represented the four control points of the linear membership function (see fig. 30). The first point (a) marks the location where the membership begins to rise above 0; this point was represented by the lowest value of the IU confidence intervals when malaria is not suitable (0). The second point (b) indicates the location where the memberships function reaches 1; this point was represented by the lowest value of the IU confidence intervals when malaria is suitable (1). The third point (c) marks the location where the membership grade begins to drop again below 1; (c) was represented by the highest value of IU confidence intervals when malaria is suitable. The last point (d) represents the point marks where membership function returns to 0; this point was represented by the highest value of IU confidence intervals when malaria is not suitable (0).

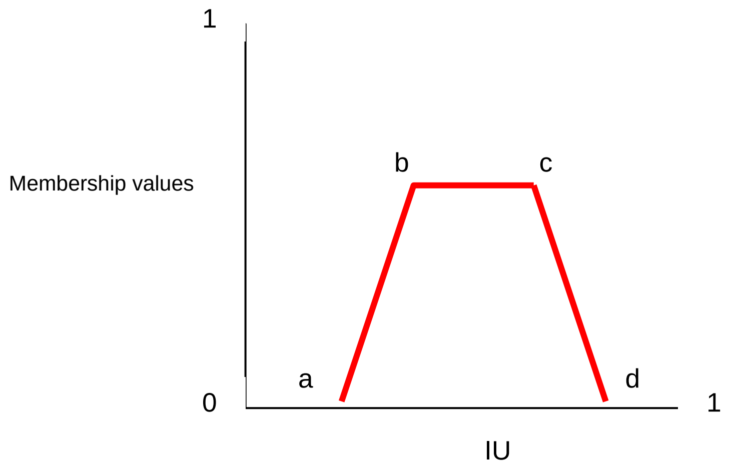


Figure 30: Definition of the linear membership functions of the urban malaria Fuzzy Logic model

This fuzzification process was performed in Idrisi Taiga. It was then followed by a defuzzification procedure. Decision maps as well as tables describing the final membership degree (between 0 and 1) of each IU-pixel were elaborated. Pixels with a membership value equal to 0 were considered as expressing absence of malaria, while the other pixels were expressing different degrees of malaria presence. All these steps (from the fuzzification to the decision) were performed for each distinct PA.

In order to evaluate the performance of the prediction, households points from field surveys were used to extract values from the final Fuzzy maps. It was possible to compare observed malaria to Fuzzy-based predicted malaria. The comparison was based on simple statistical counting of points where malaria was present (1) or absent (0). An additional spatial comparison was made on the basis of districts of the city. Mean values of both observed malaria and Fuzzy-based predicted malaria were calculated for each district and results statistically and graphically compared.

4 Socio-ecological factors are the most important

4.1 Malaria in Yaoundé is seasonal and age dependant

With 487 febrile cases (61.63 %) and 302 clinical cases (38.37%) from all the malaria cases identified in a total surveyed population of 8885 individuals (not households), the yearly (2006) malaria prevalence rate in Yaoundé is of 9 %. This prevalence rate remains very low compared to surrounding rural areas (BONNET et al., 2003). The higher prevalence rate of febrile cases indicates a low number of clinical cases of malaria in Yaoundé. The monthly variations of presumed febrile and clinical malaria cases are synchronous and positively correlated at CI=99% (see fig. 31). This result allowed considering the addition of the two data sets together in further analysis.

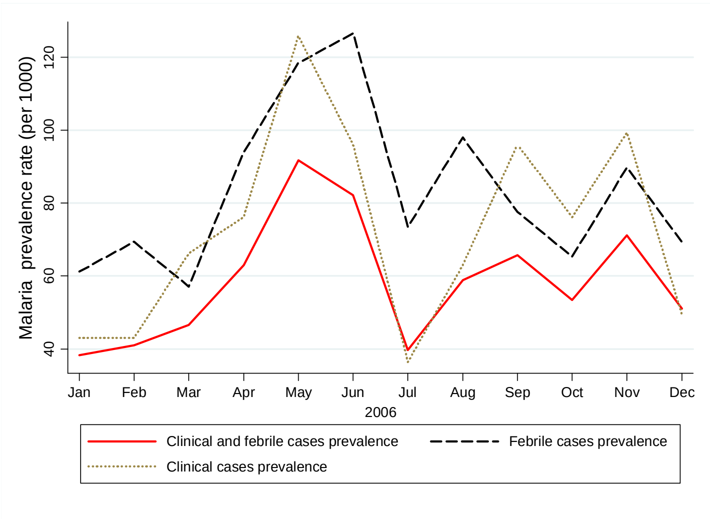


Figure 31: A seasonal synchrony between febrile and clinical malaria cases

The yearly distribution of the Malaria Relative Risk (MRR) which represents the measurement of an odds in households higher than the mean of all the survey, logically shows a high frequency of households exempt from malaria cases (see fig. 32). The highest MRR value which corresponds to households that experienced the highest number of malaria episodes is not frequent. It can denote the weighting effect of the seasonality of malaria (see chapter 4.1).

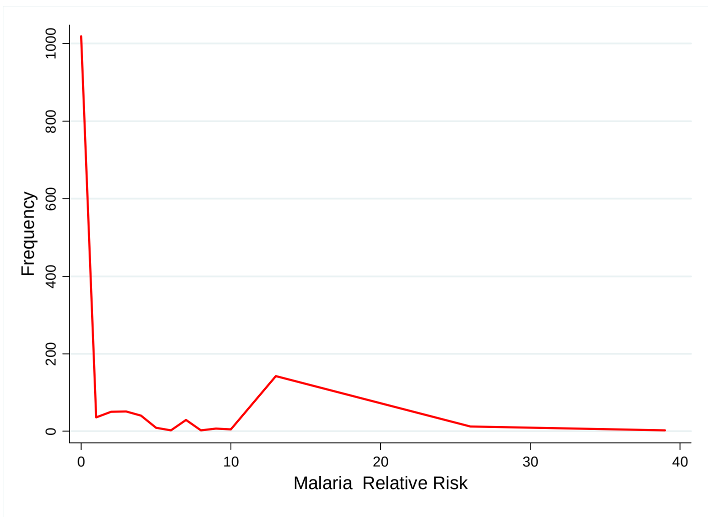


Figure 32: Frequency of the distribution of Malaria Relative Risk

The spatial representation of MRR shows a higher presence of hot spots in the peri-urban areas (see fig. 33). The peri-urban parts of the districts of Soa, Ekoumdoum, Ahala, Simbok, Nkolbisson and Mbankolo are concerned. However there is an important hot spot in the central areas that integrates the densely populated district of Briqueterie and parts of Mokolo, Madagascar and Nlongkak districts. Parts of central districts of Essos-nord, Dakar and Ekounou also have MRR hot spots. It can be concluded from the map that malaria in Yaoundé is not exclusively present in peripheral areas, even if it is more prevalent there.

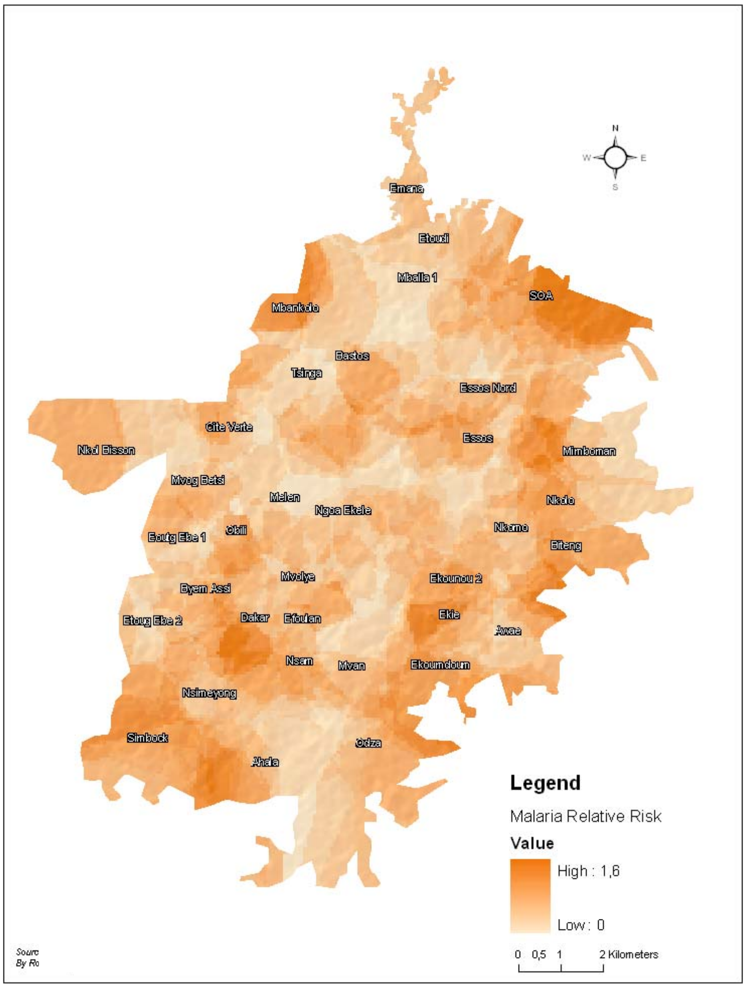


Figure 33: Spatial distribution of the malaria Odds risk

The seasonality of this prevalence is revealed by that of rainfall. The highest numbers of malaria cases are observed during the small rainy season (April-June), while the dry seasons (December-March and July-August) are marked by a decrease in the number of malaria cases (see fig. 34). In addition the correlation between rainfall and malaria prevalence is positive and significant at CI=95%.

The rainfall-data considered within the current illustrations are those of the station of Nsam. The rainfall variability of this station in the year 2006 is graphically and statistically consistent with its historical variation from 1990 to 2000 (see fig. 35). It means that there is no rainfall anomaly within the year 2006. Based on this evidence and on the high positive and significant correlation of rainfall and malaria prevalence in 2006, it can be deduced that the variability of malaria prevalence for the year 2006 is consistent with historical yearly variations of malaria at least between 1990 and 2000. However, this assumption should be tempered by the fact that it only considers climate variables, notably rainfall.

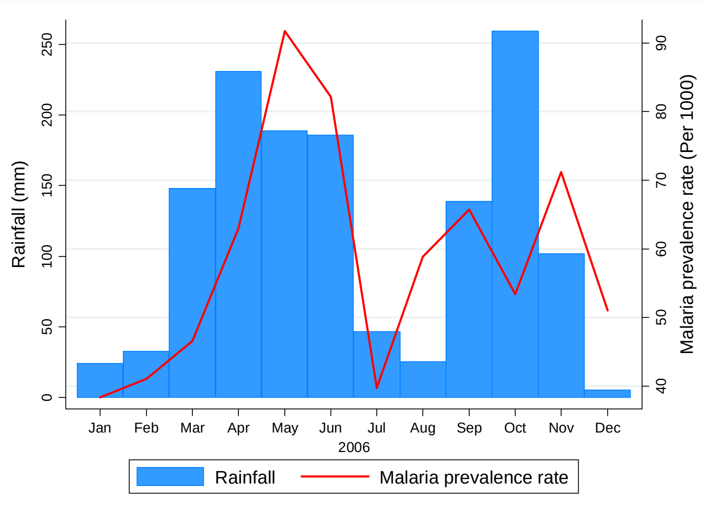


Figure 34: Rainfall and malaria prevalence

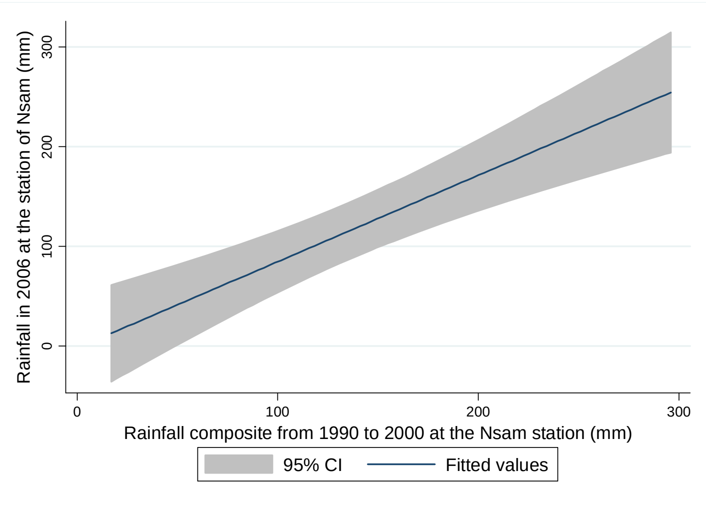


Figure 35: Rainfall in 2006 vs. Historical composite rainfall variation of the station of Nsam

Although thresholds of mean temperatures values remain favourable to a good development of malaria life cycle during the whole year (despite an increase during the dry season), they are not decisively intervening into the variations of malaria cases. Temperatures were not significantly correlated with malaria prevalence. Although the relative humidity is a good indicator of the presence of potential breeding sites, its relationship to malaria prevalence was not statistically significant (see fig. 36)

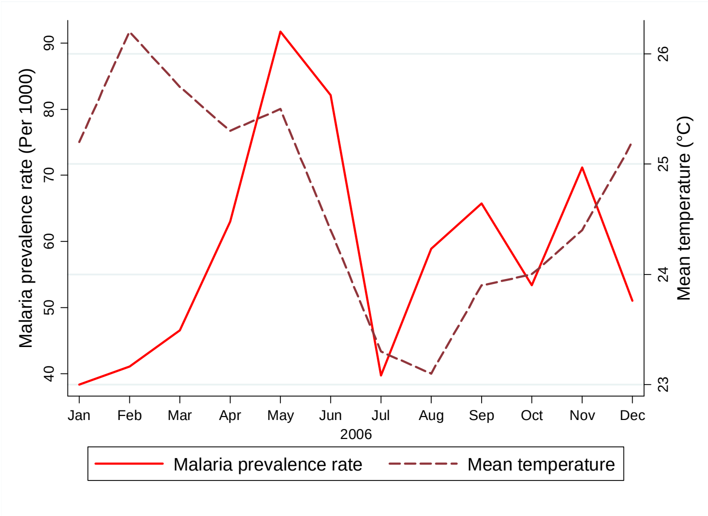


Figure 36: Malaria prevalence vs. Mean Temperatures

The seasonal spatial distribution of MRR shows a quasi-exclusive presence of hot spots in peri-urban districts during the small rainy season (see fig. 37). The districts of Soa, Ekoum-

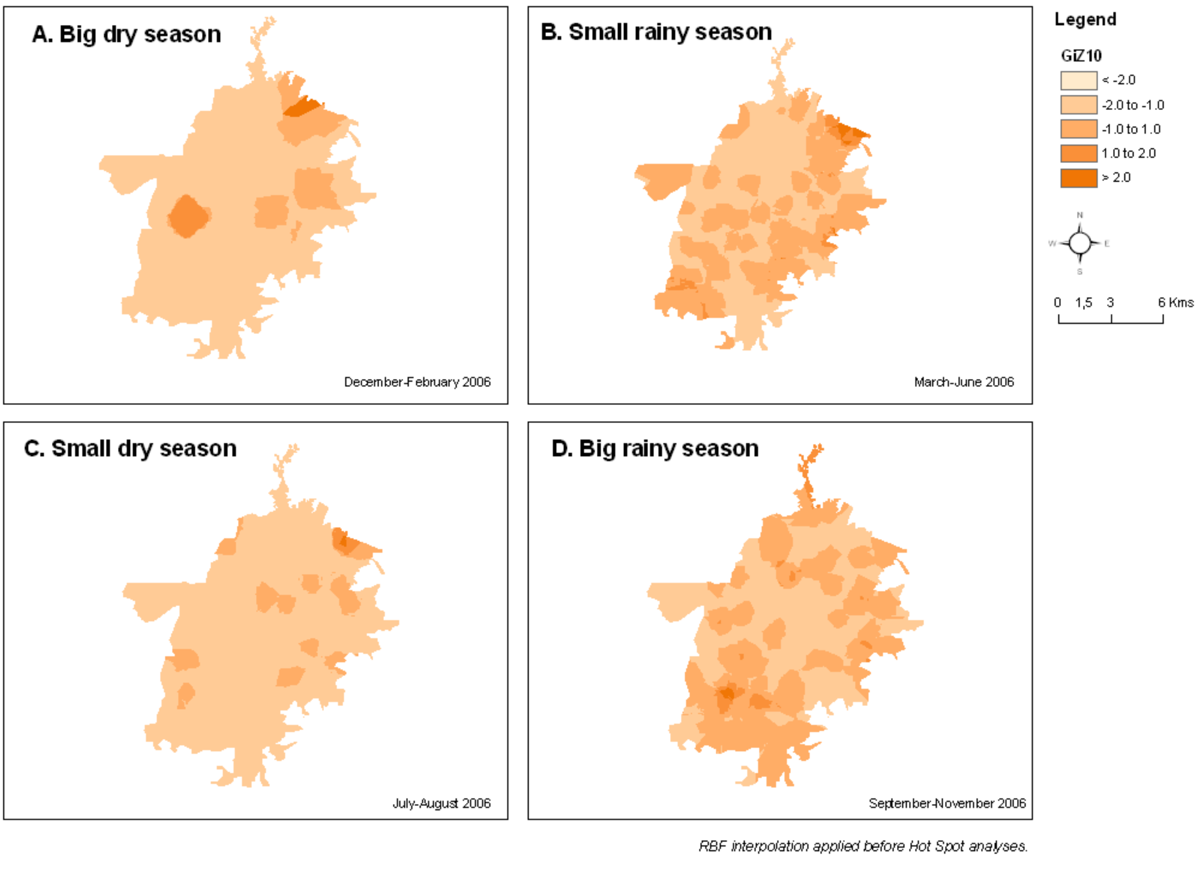


Figure 37: Seasonal hot spots of Malaria Relative Risk (MRR) in Yaoundé

doum, Simbok, Ekounou and Mbankolo are concerned. This finding gives a particular value to these peri-urban areas since the small rainy season is the one that contributes the most to the yearly malaria prevalence. The big dry season also shows hot spots in the peripheral areas.

The big rainy season is marked by an important presence of hot spots in central areas. This spatially centralized distribution of malaria areas is also visible during the small dry season, although it is weighted by the presence of two important hot spots in the districts of Soa and Mbankolo. The possible factors explaining this spatial seasonal distribution of MRR will be mentioned in Chapter 4.3.

The age-standardization of malaria incidence showed a standardized incidence-rate R_{As} with a value equal to 2.02%, inferior to that of the specific incidence rate R_{Ai} with a value equal to 9% (see fig. 38). These figures suggest that malaria is age dependent in Yaoundé. Despite the fact that the under-five age group are not the most represented in the population (INSTITUT NATIONAL DE LA STATISTIQUE, 2002), their specific and standardized incidence rates (16%) are superior to tho-

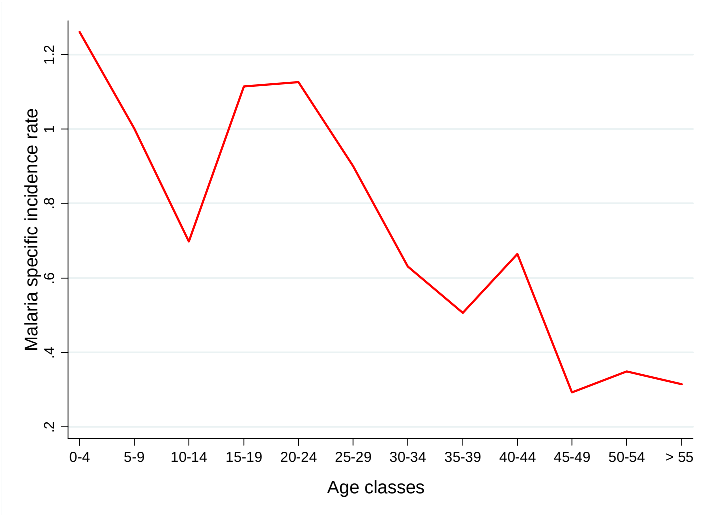


Figure 38: Specific incidence rate of malaria

-se of all the age categories. They are closely followed by the category of age between 5 and 9 (14%) and that of the category between 15 and 19 (see fig. 38). The category between 20-24 are the most represented in the population; their specific and standardized incidence-rate is also important. Adults are less subject to malaria episodes than young (see fig. 38 and fig. 39).

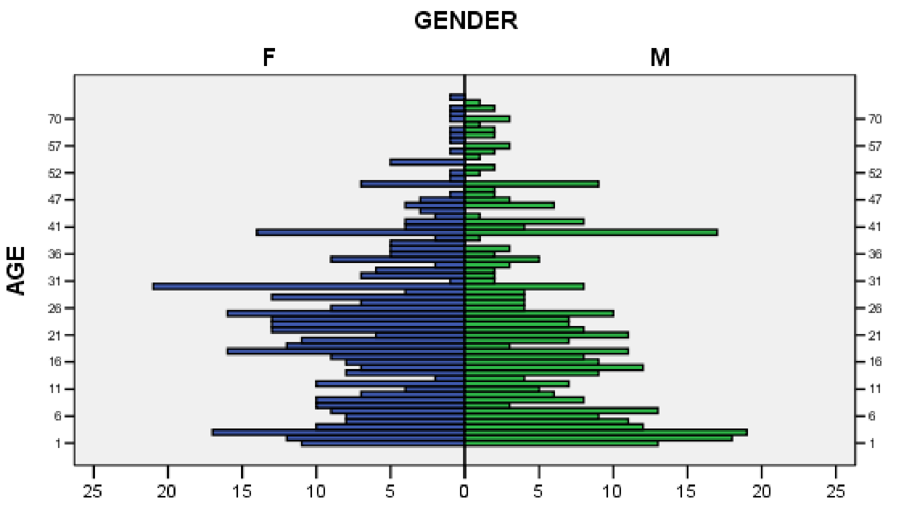


Figure 39: Pyramid of ages of malaria cases during the year 2006

Although these findings were of a great importance, they did not lead to an exclusion of some categories in the current study. This decision was based on the assumption that adults are subject to severe malaria episodes. Since they did not develop resistance or immunity against malaria, they are likely to experience very severe (fatal) malaria episodes (SEVEROV et al., 2000; BAUDON & SPIEGEL, 2001; BREMAN, 2004).

4.2 Social variables contribute more to MRR than natural variables

After commenting on the spatial and seasonal configuration of MRR, the currrent chapter presents the results of the statistical multinomial analyses. It identifies key ecological and social variables associated with the MRR. It also shows how groups of variables with thematical proximity contribute to the presence of malaria. The results of the multinomial modeling procedures are finally a statistical way to predict malaria using variables of various nature. The variety of the nature of these variables is a useful base for antimalarial prevention strategy based on a sectoral approach.

4.2.1 A non-significant spatial variation of rainfall values

As stated in Chapter 3.7, climate variables were not considered in the multinomial regressions, simply because the network of local climate stations was too poor to allow reliable spatial interpolations before introduction into the Mlogit-model. However, this spatial unreliability of climate variables led to the question to know whether there was really a need to have a denser climate network. In other words: Are climatic processes not too global to expect the existence of a spatial micro-variability? In order to make a snapshot investigation on these questions, two approaches were considered: investigating some local ecological differences of the available climate stations and introducing rainfall estimates (RFE) data. The assumption associated with the first idea was that local ecological differences can indicate climate micro variability (SIEGMUND, 1999).

Although it is empirically evident that comparing only two climate stations is not sufficient to detect a robust spatial micro variability of the entire city, the procedure gave interesting results. Mean elevation values are higher in Nsam than in Nkolbisson (see fig. 40 and tab. 18). Accordingly, slopes values are higher in Nsam, and NDVI values are higher in Nkolbisson. Hillshade values are also higher in Nkolbisson than in Nsam.

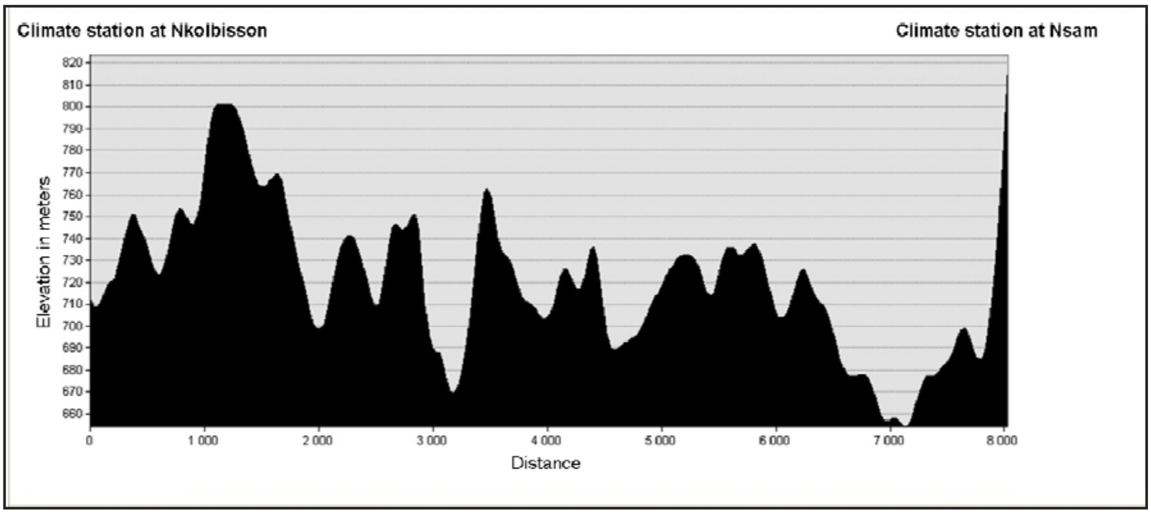


Figure 40: Topographical profile between Nkolbisson and Nsam climate stations

Variables	Stations		Comparison
	Nsam	Nkolbisson	Variance
Minimum elevation value	668	668	0
Maximum elevation value	883	776	5724.5
Mean elevation value	740	711	420.5
Minimum slope value	0.4	0	0.08
Maximum slope value	51	25	338
Mean slope value	20	8	72
Minimum NDVI in wet season Value	-0.4	-1	0.18
Maximum NDVI in wet season Value	0.45	0.63	0.0162
Mean NDVI in wet season Value	0.05	0.07	0.0002
Minimum Hillshade value	0	117	6844.5
Maximum Hillshade value	253	239	98
Mean Hillshade value	166	188	242

Table 18: Chosen local ecological indicators of the stations in Nsam and Nkolbisson

Results of bivariate analysis between the two stations showed a very high positive correlation (R=0,95) between rainfall in Nsam and rainfall in Nkolbisson. This correlation is positive at 99% confidence intervals. This result denotes a general synchrony between the two stations (see fig. 41). However, when comparing the annual mean and total values received by the two stations, it turns out that Nsam with a total of 857 mm received less water than Nkolbisson with a total of 1.281 mm.

On the other hand, temperatures between the two stations were not significantly correlated. There were important differences between the two stations. However, temperature values of both stations remained within the threshold values to a favourable development of malaria life cycle (HAY et al., 1996; OMUMBO, 1998).

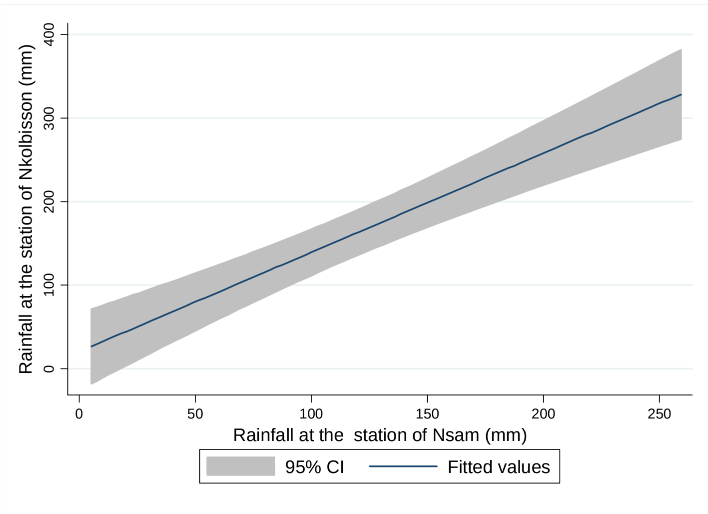


Figure 41: Fit between rainfall in Nsam and rainfall in Nkolbisson

Results of bivariate analysis between the referent station of Nsam and rainfall estimates (RFE) data showed a significant positive correlation (R=0.74) at CI=95% (see fig. 42). The correlation was also positive and significant between rainfall at the station of Nkolbisson and RFE-extracts of the same point. Thus, rainfall estimates (RFE)-data did not offer a better spatial alternative than the ground network of stations (see fig. 43).

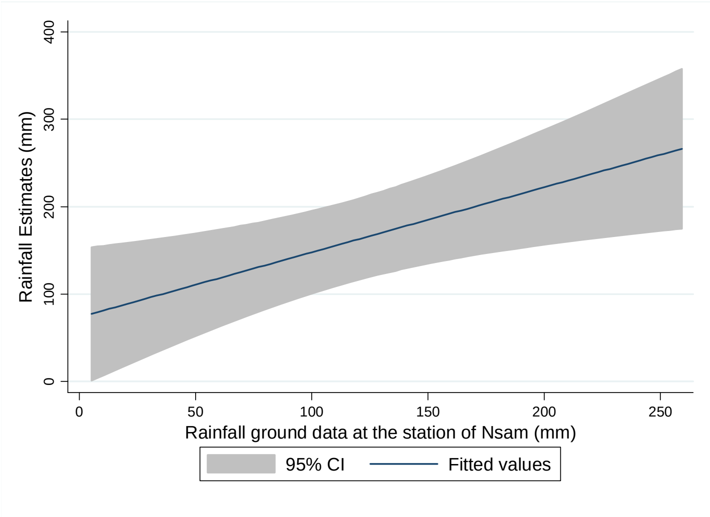


Figure 42: Fit between rainfall estimates (RFE) and rainfall in the ground station of Nsam

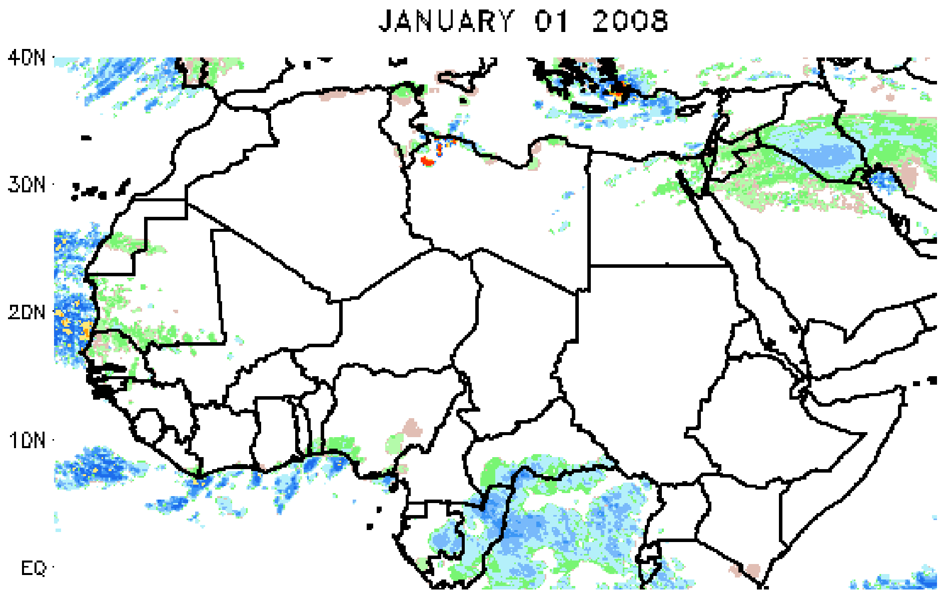


Figure 43: Example of spatial representation of rainfall Estimates (RFE) data sources (After Famine Early Warning Systems Network (FEWS). (http://www.fews.net/Pages/default.aspx))

Considering that rainfall has a more decisive role than temperature and relative humidity in their relationship to malaria (see chapter 4.1), many assumptions can be made from these results.

- Rainfall-data result from a too global process to allow spatial micro-variability between two points having a distance of 8 km between each other.
- Local ecological variables integrated in this analysis do not have physical characteristics to allow a significant variability of rainfall.
- More stations would be needed to detect micro-variability of rainfall values.

4.2.2 Vegetation, vegetation indexes and water bodies are not significant

Among the LULC-classes obtained from the classification of satellite images (see fig. 44), vegetation and water bodies were assumed to have the highest potential to host potential breeding sites. However, other features like bare soils and paved areas were included in bivariate analyses. In fact, their proximity to households (a mean distance of 9 and 12 m respectively for bare soils and paved areas) allows bare soils and paved areas to be good potential supports of artificial breeding sites. Despite this proximity to households (see fig. 45), the results shows a negative and non-significant correlation with the Malaria Relative Ri-

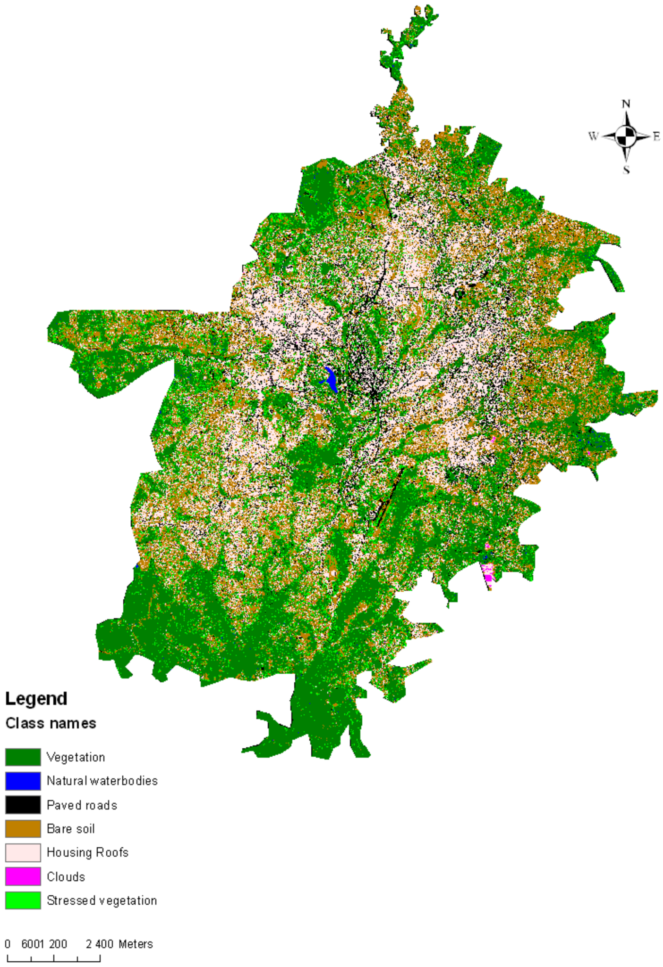


Figure 44: Land Use and Land Cover LULC classification of Yaoundé

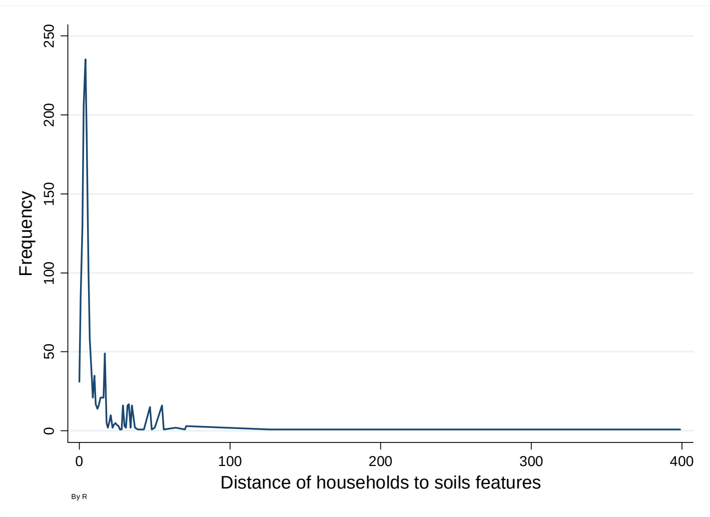


Figure 45: Household's distances to Soils

sk (MRR). The hypotheses should be that QuickBird data spatial resolution (0.6 m-2.4 m) is not high enough to allow the detection of artificial breeding sites, notably at a household level. The potential artificial breeding sites intrinsically contained within bare soils and paved areas are simply not significant predictors of MRR.

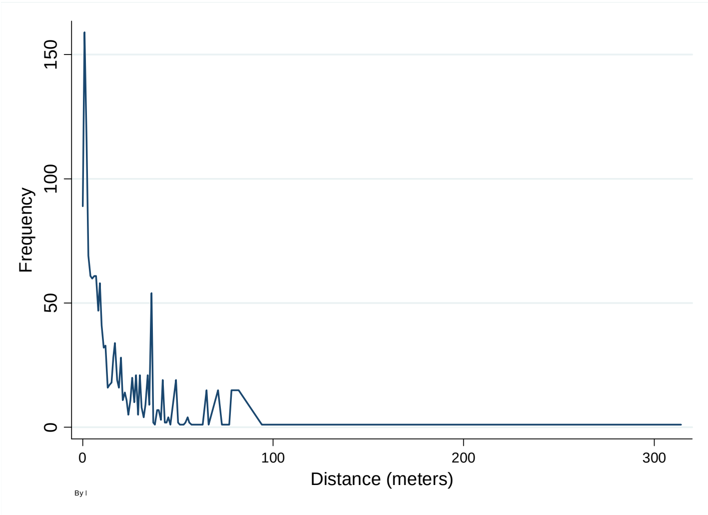


Figure 46: Household's distances to vegetation

With a mean distance to households of 16 m (see fig. 46) patterns of vegetation were also not significantly correlated with MRR. In any event, this variable was thematically too closed to the Normalized Differenced Vegetation Index (NDVI), even if NDVI did not only integrate values of vegetation and all the other LULC-features NDVI values of each of the LULC-features were extracted for dry and rainy seasons (see fig. 47).

They were used as seasonal proxies' values for the entire selected seasons. The comparison between the NDVI values during the rainy seasons and NDVI values during the dry seasons naturally showed higher values during the rainy season. The results of the analysis of NDVI categories distances to households showed that distances values were proportional to NDVI values. The higher is the NDVI value, the higher is the distance to households. It simply means that the largest part of households is at an important distance to highest NDVI values. Only 0.8% of the total surface of Yaoundé had favourable thresholds NDVI values of 0.51 to 1 (OMUMBO, 1998) during the wet seasons. The mean household distance to this NDVI category is 1,015 meters. It presented no significant correlations with MRR. The mostly represented NDVI values are respectively that of classes between of -0.5 to 0 and 0 to 049. They were respectively representing 51% and 41% of the administrative surface of the city, with respective mean nearest distances of 12 and 16 m. None of these categories are significantly associated with MRR.

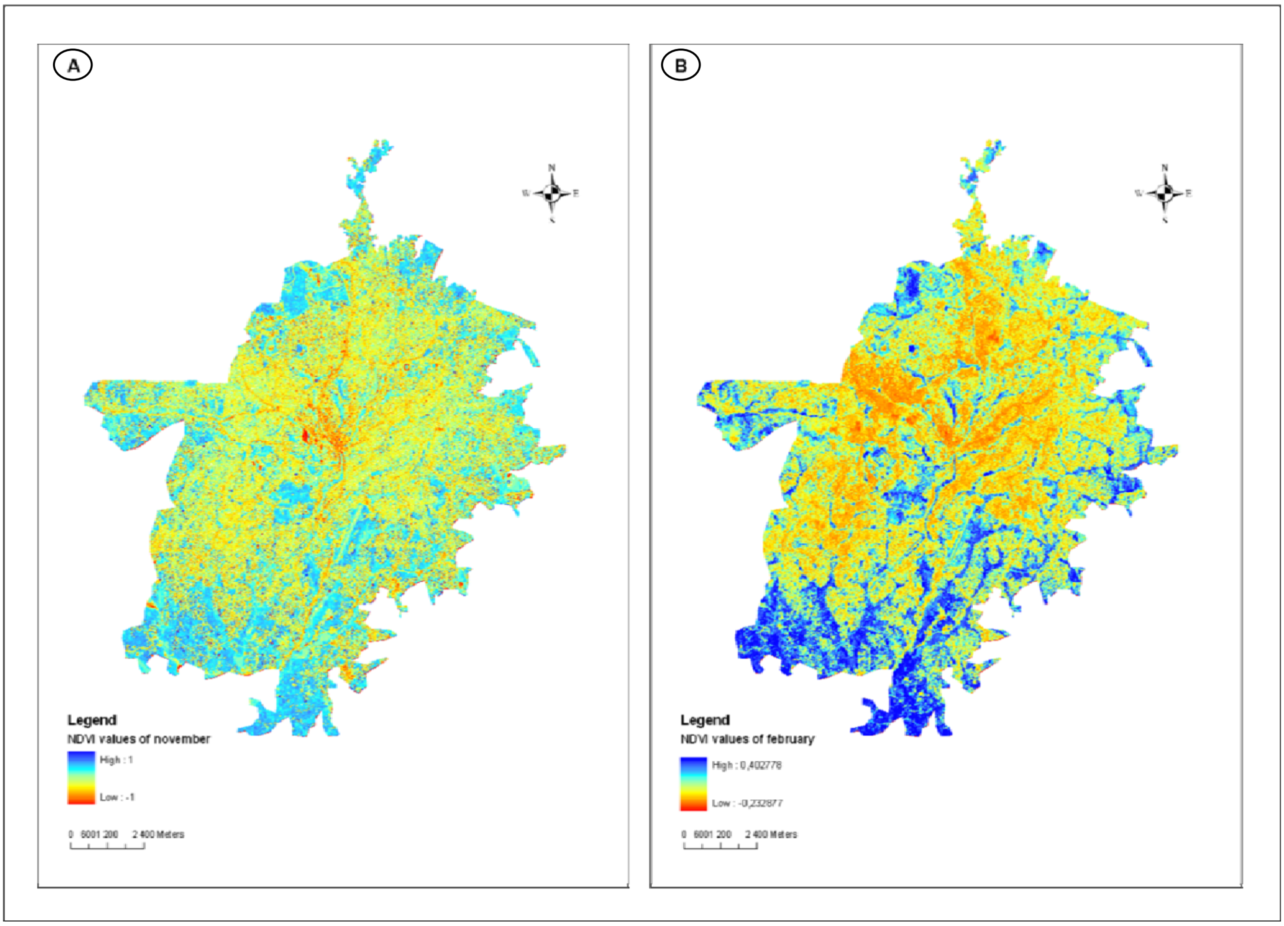


Figure 47: Normalized Differenced Vegetation Index (NDVI) in dry (A) and rainy (B) seasons

The mean distance of households to water bodies was 369 m which is higher than that of favourable NDVI values. Results of graphical analyses show that MRR is diminishing proportionally with the distance to water surfaces (see fig. 48). However, the association between those two variables is not significant.

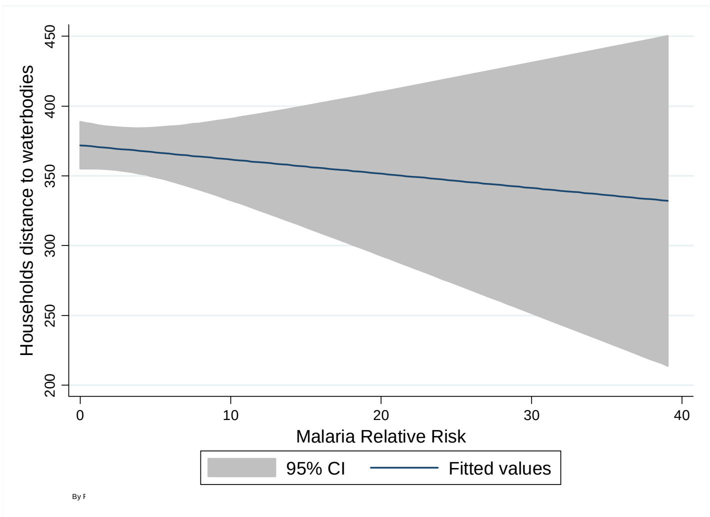


Figure 48: Fit between households distance to water bodies and Malaria Relative Risk (MRR)

It is possible that the speed and intensity of the water flows do not allow the development of vectors (mosquitoes). In fact, Yaoundé is regularly subject to important flooding episodes (ASSAKO ASSAKO, 1998; TCHOTSOUA, 2007) (see fig. 49).

Figure 49: Flooding in Yaoundé (TCHOTSOUA, 2007)

It is also possible that waste of human origin does not favor the development of malaria vectors (see fig. 50). In fact, the most dangerous vector species such as *An. gambiae* prefer stable water pools (MOUCHET & CARNAVALE, 1998) which are not easily detectable with remote sensing technology. For all these reasons, agricultural areas constitute an important ecological feature. Agricultural activities create water pools in the vicinity of visibly more prominent water bodies.

Figure 50: Example of human waste in the district of Cité verte in Yaoundé (July 2007)

4.2.3 Agricultural patterns and elevation values are associated with the Malaria Relative Risk (MRR)

Authors have argued that the topography of Yaoundé is an image of its socio-economic profile. They observed that rich people were living in the highest altitudes while poor people are colonizing the valleys (ASSAKO, 1998). These observations are sensible having regard to agricultural activities. As already discussed (see Chapters 2.5 and 3.8.5), agriculture is an important domestic and economic activity in Yaoundé (KENGNE, 1997; BOPDA, 2003). When walking through the city, one can observe that various types of agricultural activities are developed along the water drains (see fig. 51). One can also notice the presence of slums in the vicinity of those water drains.

However, what should be stressed from the results of the analyses is that Yaoundé is definitively a hilly town (see fig. 52). The mean elevation value of houses from the survey was 724 meters. Less than 1% of these houses had an elevation value of less than 600 meters. Their mean slopes value was of 12°. Since elevation and slopes are highly naturally correlated, and considering that the general shape of the relief is very irregular (see fig. 40 in Chapter 4.2.3), it can be suggested that high slopes values are also well distributed in Yaoundé. It means that the natural probability for a household to be situated in a valley is less high than the probability to be situated on a slope, or on the top of the hill. The question is to know whether this probability is imbalanced by socio-economic realities.

Figure 51: Floriculture in the district of Centre administratif in Yaoundé (Image: July 2007)

The correlation between elevation values and the Economic Capacity (EC) of households is slightly positive with a correlation coefficient value of 0.02. It suggests that the richest households are not situated in valleys. But this result is imbalanced by the positive relationship between the crowding coefficient and the elevation values, with a correlation coefficient value of 0.017. There is obviously no definitive extreme orientation in the design of the relationship between socio-economic status and elevation values. Moreover, these associations are not statistically significant.

The relationship between elevation values and the Index of Urbanity (IU) was positive and significant at CI=99%. It suggests that the most populated and the most urbanized parts of the city are not situated in the valleys (see fig. 53). This is confirmed by the positive and significant correlation that exists between households situated in dense population aggregates (PA) and elevation values (see chapter 4.3.1). The negative and significant correlation between isolated households and elevation values also confirms this fact.

Elevation values were negatively and significantly associated with MRR at 99% confidence interval, with a correlation coefficient value of 0.072. It means that people living in the valleys are more exposed to malaria-transmission risks. But the coefficient value suggests that this correlation is not high.

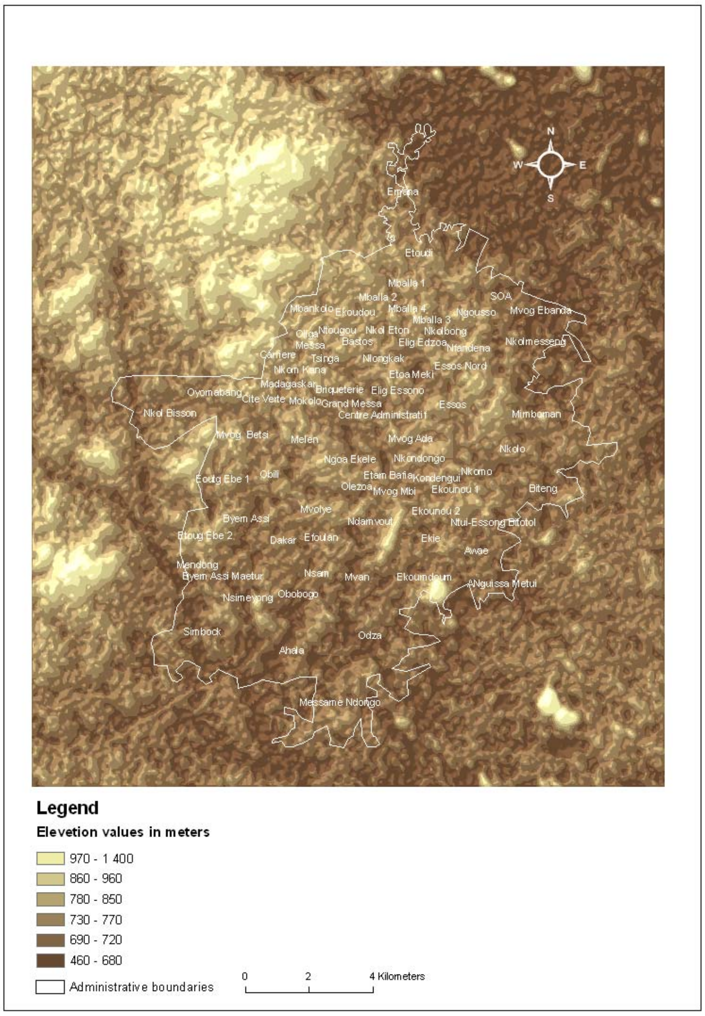


Figure 52: Topographical map of Yaoundé

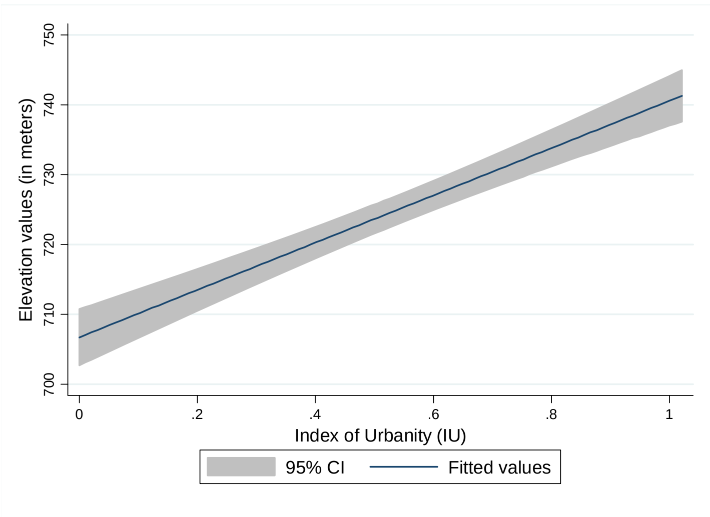


Figure 53: Elevation values vs. the Index of Urbanity (IU)

Agricultural areas with a mean distance to households of 664 m are two times farther from households than water bodies. Agricultural activities are positively and significantly correlated with malaria (CI=99% and R=0.08). At a first glance, locations of agricultural patterns correspond to those of MRR hot spots (see fig. 54). As already stated, UA areas are also mainly situated near a water drain.

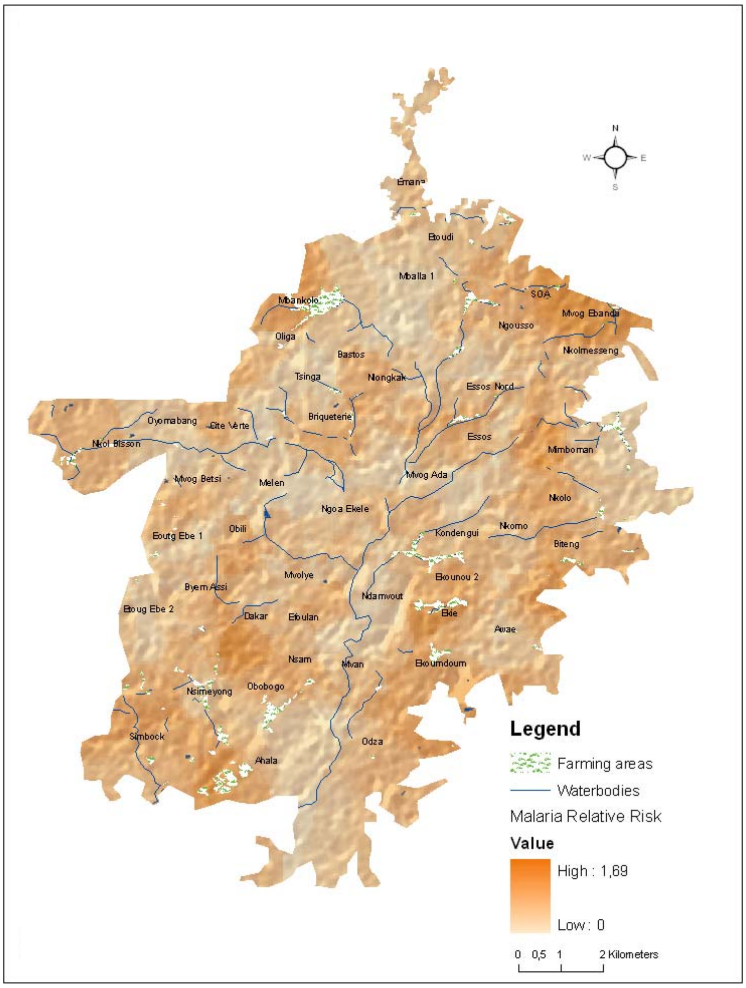


Figure 54: Agricultural zones and Malaria Relative Risk in Yaoundé

This suggests that agricultural activities are exclusively performed in valleys, which corresponds to many examples of agricultural areas elsewhere. The results of the bivariate analyses between elevation and agricultural zones show a positive and significant correlation (CI=95%) between those two variables. The suggestion is that urban agriculture is exclusively practised in valleys.

Farming activities that were remotely extracted here are those much more practised as an extended economic activity. They include fishing activities (apiculture), floriculture and other crop cultivation (see fig. 55). Another domestic agricultural activity is practised in the immediate surroundings of households. This one is not detected or very difficult to detect by optical remotely sensed technologies. This is notably due to the much reduced sizes of the parcels and also to the confusion between natural and agricultural vegetation. While conducting field inquiries in June and July 2007 in Yaoundé, it was noticed that many of the visited households have a small parcel much more composed of maize.

Figure 55: Apiculture in Mfandena, Yaoundé (June 2007)

Although urban agriculture (UA) and elevation are significantly correlated to the MRR, their predictive capacity as revealed by the Mlogit model is not so important (see tab. 19 and fig. 56). This result suggests that these variables have a mitigating direct impact on malaria in Yaoundé. The fact that they only predicted low malaria risks suggests that the ecological vulnerability to malaria is biased by other factors less directly involved in the process of mosquitoes breeding sites production (natural conditions needed for the egg and larval stages notably). In other words, the effective transmission of malaria seems to be conditioned by social related factors. These factors will act as a filter to the effective transmission of malaria in Yaoundé. However, this interpretation does not consider climate variables.

Ecological Mlogit model prediction

Malaria	**% of correct prediction**
No malaria ($rCPK_0$)	99.80%
Low malaria risk ($rCPK_1$)	2%
Middle malaria risk ($rCPK_2$)	0%
High malaria risk ($rCPK_3$)	0%
Malaria presence correct prediction (r_{mpp})	0.77%
Predicted malaria prevalence (P_{mP})	1%

Table 19: Statistical results of the ecological model

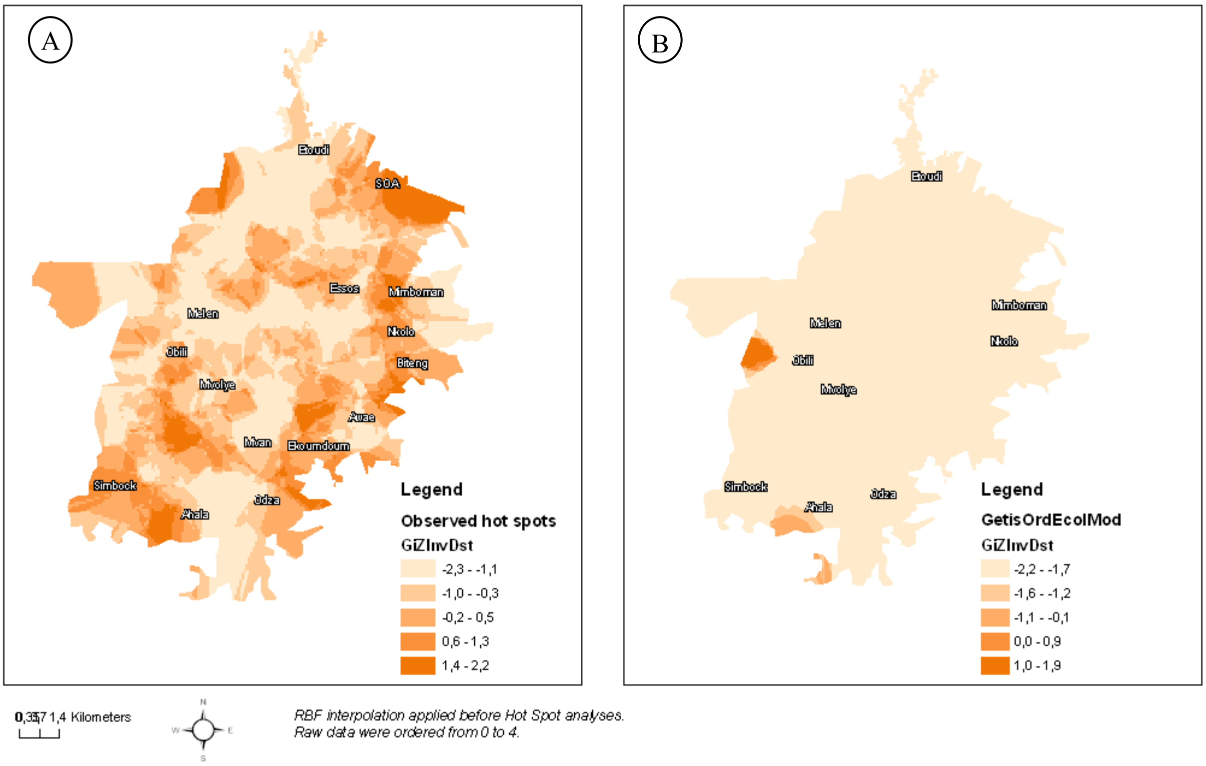


Figure 56: Comparison between the spatial representations of observed malaria (A) and predicted ecological model (B)

4.2.4 Economic capacity and socio-environmental variables have the most predictive potential

4.2.4.1 Economic capacity (EC) an important transversal indicator of malaria risks

With a contribution of 16% of the correct predictions, the socio-economic variables are among the most important explanatory variables to the presence of malaria (see tab. 20 and fig. 57). The Economic Capacity (EC) is assumed to draw the distribution of other social variables (INACK INACK, 1995; DIRECTION DE LA STATISTIQUE ET DE LA COMPTABILITÉ NATIONALE, 2002). In fact, many social characteristics of individuals/households, such as prevention capacity, crowding state, depend on the financial capacity of these households. The association of the EC with social variables was not analysed in a sociological comprehensive way. This means that factors such as educational level or other possible potentially relevant factors were not considered, because of their non-association to malaria risks or simply because the level of their abstraction was too high for an extensive concern within this study. Priority was given to factors for which quantification and control in terms of direct physical or economical action was obvious.

Socio-economic Mlogit model prediction

Malaria	% of correct prediction
No malaria	83.12%
Low malaria risk	0%
Middle malaria risk	0%
High malaria risk	21%
Malaria presence correct prediction (r_{mpp})	16.00%
Predicted malaria prevalence (P_{mP})	7.31%

Table 20: Statistical results of the socio-economic model

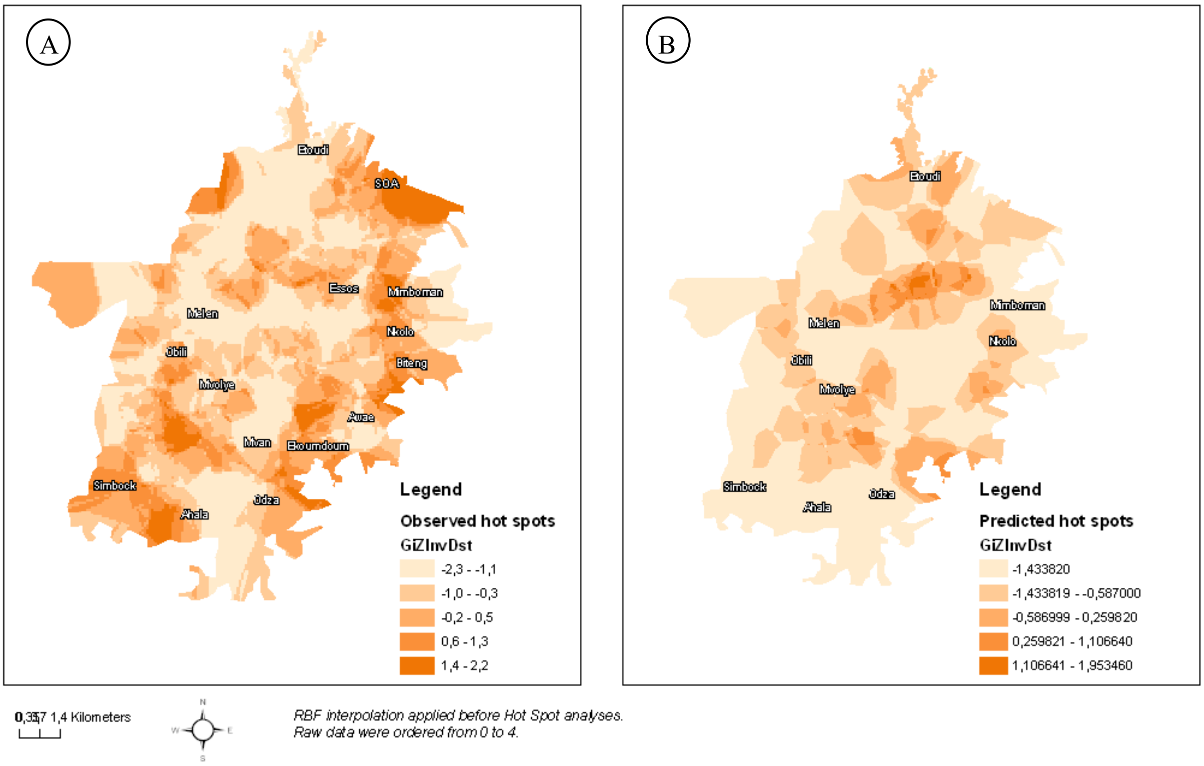


Figure 57: Comparison between the spatial representations of observed malaria (A) and predicted socio-economic malaria model (B).

The results of these transversal analyses showed that the crowding coefficient was very high for the poorest households (households with the lowest EC) (see fig. 58). They also showed that the prevention capacity is higher among the richest households (see fig. 59). However, the EIG-coefficient, defining the regular cleaning of the environment, the utilization of insecticides and the presence of protective grids on windows, is higher among the poorest households than the richest. This denotes the fact that the poor people are more involved in cleaning their surroundings than the rich people, which is in logic with the high present level of crowding. It could also mean that the poorest do not have the financial capacity to access a higher protection level against malaria. This higher protection level is notably identified by the utilization of insecticides and mosquito nets. This inaccessibility can also be associated with other factors such as level of malaria-knowledge (see Chapter 5.1.1) and information about other means of prevention (drug intakes). The poorest households also have the highest presence of external toilets, which is an important part of the crowding coefficient.

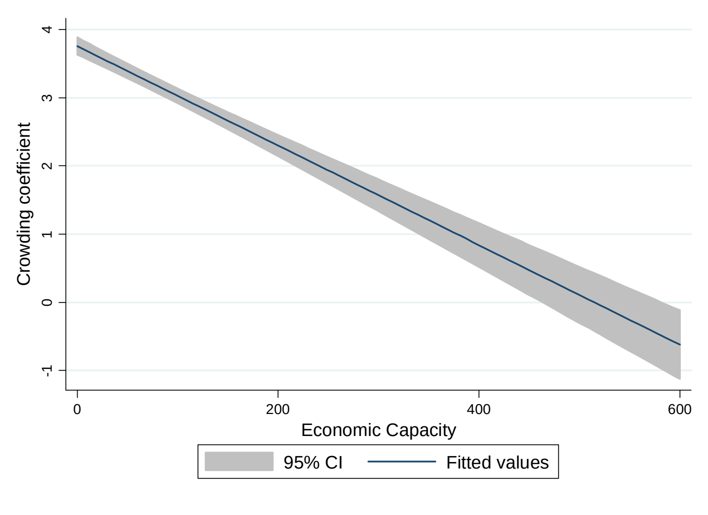


Figure 58: Fit between Economic Capacity and crowding coefficient

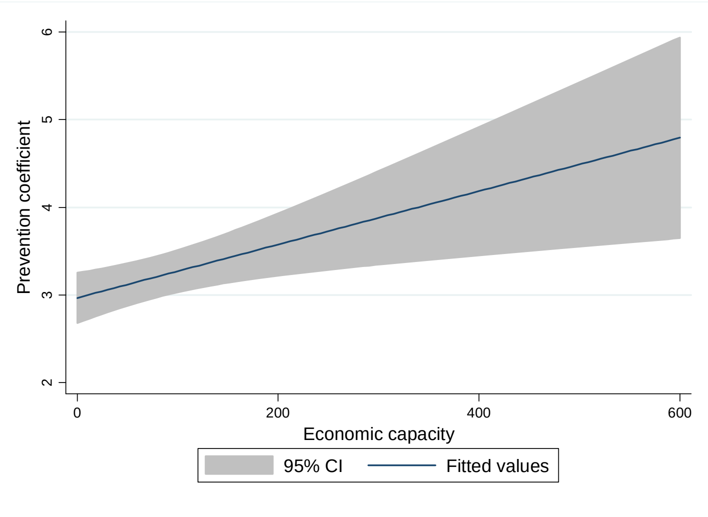


Figure 59: Fit between Economic Capacity (EC) and prevention coefficient

As was expected, the EC also stratifies the distribution of the employment and employment sectors. People involved in informal activities (78% of the survey) were belonging to households having the lowest EC (see fig. 60). Civil servant and other categories were positively and significantly associated with the EC.

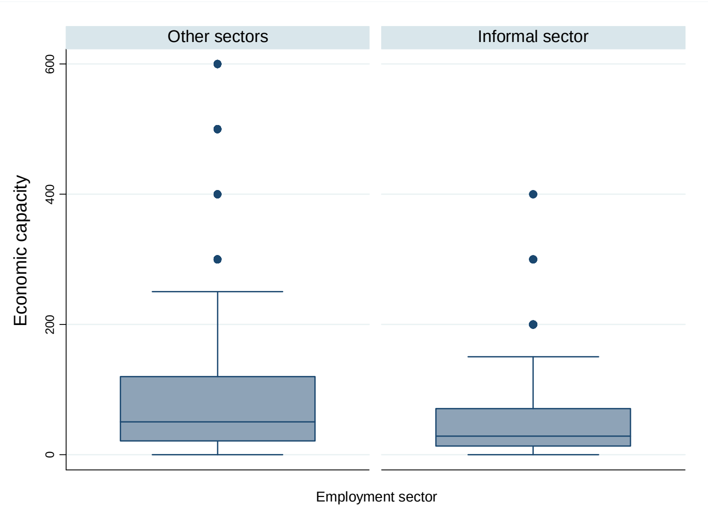


Figure 60: Economic Capacity by informal and non-informal sectors of economic activity

The spatial distribution of the EC shows a concentration of richest people in the central planned residential districts of Essos Nord, Elig-Essono, Centre administrative, Nkolbong (Popular name Bastos), and also in the more recently-built, planned residential areas of Biyem-Assi Maetur, Obobogo, Mballa 3, and Mballa 4. The poorest hot spots are located in central densely populated areas covering the districts of la Briqueterie, Elig. Edzoa, Mvog Ada, Nkolndongo, Kondengui, Nkomo and Etam Bafia. The peripheral, but less rural, spontaneous areas covering the districts of Mimboman and Nkolmesseng also have many poor households. The more rural districts of Anguissa Metui, Awae, Ekie, Ndamvout, Messame Ndongo, and Odza are also characterized by poverty (see fig. 61).

There is no spatial uniformity in the distribution of poverty indexes in Yaoundé. Rural patterns in peripheral areas show an important presence of poor households. As will been seen in Chapter 4.3.5, the most densely populated areas which are also the poorest are situated in central areas. This distribution has an incidence on the distribution of the malaria risk.

MRR is positively correlated with the EC (see fig. 62), which means the poorest populations are less exposed than the richest. This is a surprising result since poverty is usually positively associated with malaria. Explanation of these results will be given in Chapter 4.3.5, which analyses the morphological-structure of the city in relationship with both ecological and social variables.

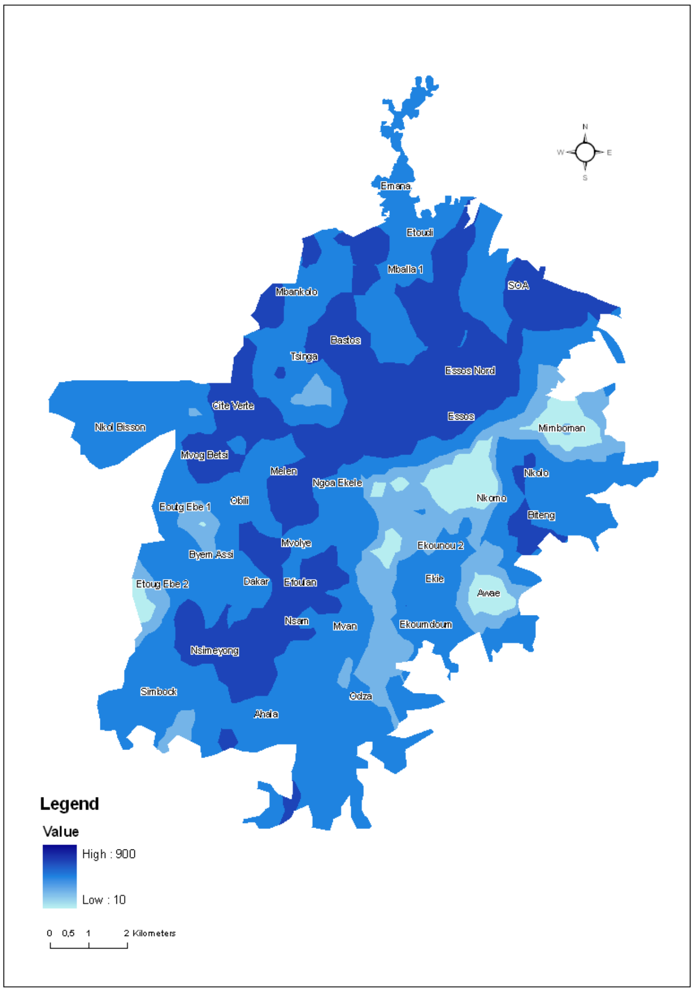


Figure 61: Spatial distribution of the Economic Capacity

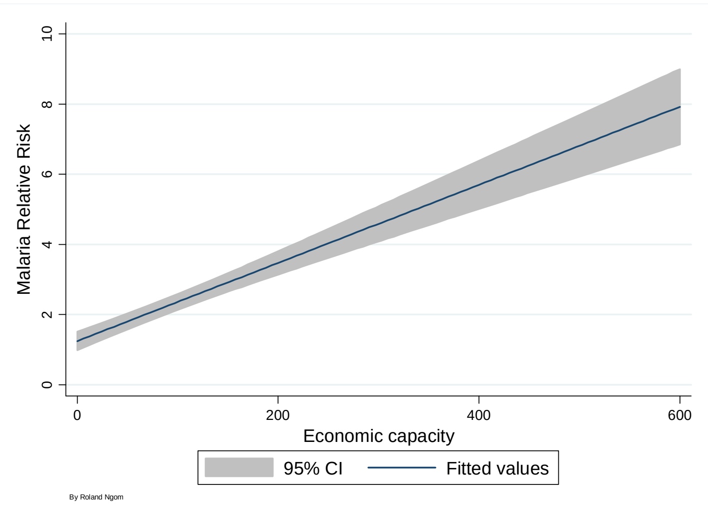


Figure 62: Fit between Economic Capacity (EC) and Malaria Relative Risk (MRR)

4.2.4.2 Crowding highly contributes to malaria risk

Among the socio-ecological factors (factors that are associated with environmental characteristics of the households and at a household level), the one that illustrates the crowding are those that contribute the most to the MRR. The room crowding coefficient R_c bears the most important predictive potential within the socio-ecologic model. The higher the density of people in a room, the higher they are exposed to malaria. This conclusion is in line with results of biological studies that demonstrated that *Anopheles* choose a human recipient according to a metabolism associated with human odours (ERNST et al., 2006; TAKKEN & KNOLS, 1999). Toilets that are apart from the main house building also constitute an important malaria risk factor. Households that are physically isolated from others significantly contribute to the exposition to malaria. By explaining a total of 39% of the correct prediction, the socio-ecological model performed the best in predicting malaria presence in Yaoundé (see tab. 21 and fig.63).

Socio-ecological Mlogit model prediction

Malaria	% of correct prediction
No malaria ($rCPK_0$)	90.97%
Low malaria risk ($rCPK_1$)	0%
Middle malaria risks ($rCPK_2$)	0%
High malaria risk ($rCPK_3$)	39%
Malaria presence correct prediction (r_{mpp})	39%
Predicted malaria prevalence (P_{mP})	6.65%

Table 21: Statistical results of the socio-ecologic model

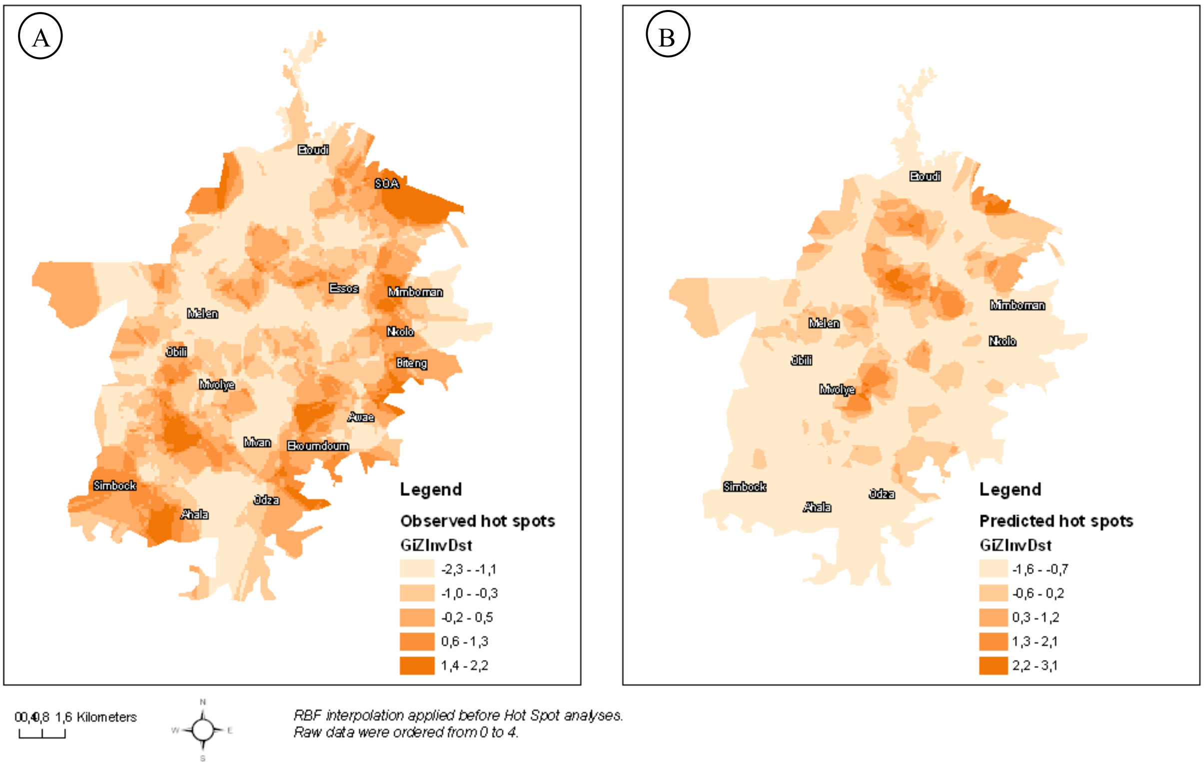


Figure 63: Comparison between the spatial representations of observed malaria (A) and predicted socio-ecological model of malaria (B)

The crowding coefficient presents hot spots in both central and peripheral areas. Areas of high EC, such as the corridor between Centre Administratif-Essos and Elig-Essono, have a low crowding coefficient (see fig. 64). What is remarkable is the presence of the large MRR central hot spot area of the Briquetrie and parts of surrounding districts. On a pure simple statistical point of view, peri-urban areas with rural patterns are predominantly represented: hot spots are found in Soa, Nkolo, Ekoumdoum, Etoug-Ebe. The other central hot spots are: Ngoa Ekelle, where the population is mostly composed of students, and part of Nkolndongo.

This result indicates that household crowding is a very important element explaining the vulnerability to malaria-risk in Yaoundé. This result also introduces confusion since it is assumed that the crowding coefficient is positively and significantly associated with poverty (in the perspective of EC), and that the majority of poor people (living in the city centre) are safe from malaria. The possible explanation is that the non-safe part of the poor people is concerned here. Another possible explanation is that the majority of people not living in the central population aggregates (PA) of the city are vulnerable to malaria. This vulnerability is mainly associated with the crowding conditions of their households, regardless of their EC (see fig. 65). This assumption should be analysed in regards of the morpho-ecological patterns of the city.

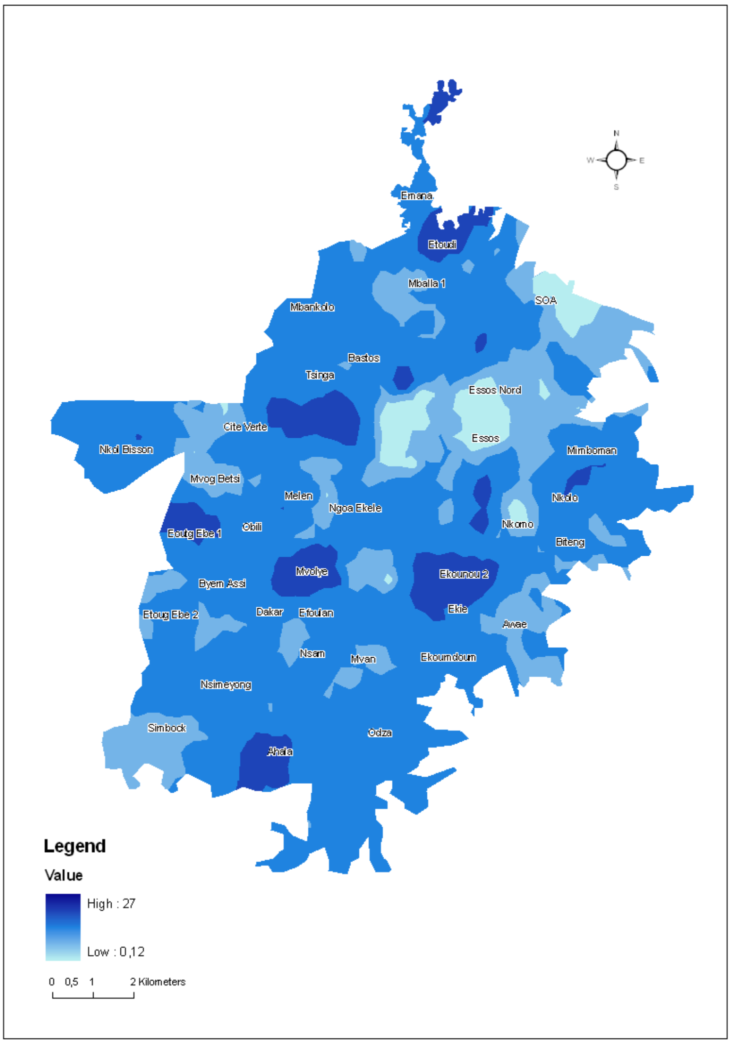


Figure 64: Spatial distribution of the crowding coefficient in Yaoundé

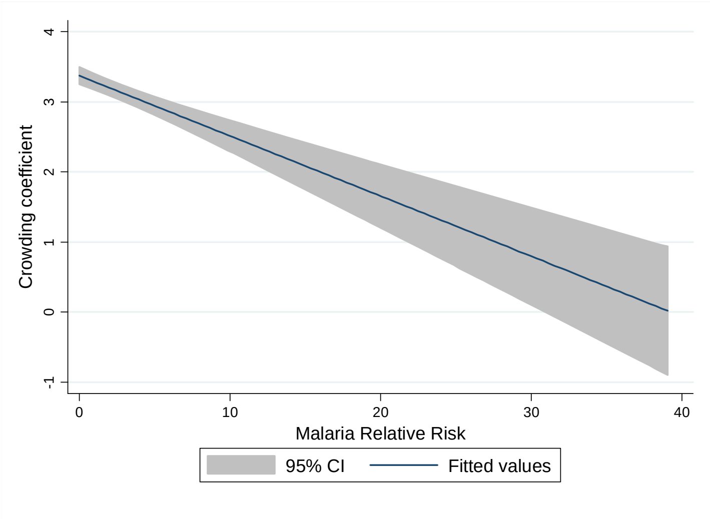


Figure 65: Fit between Malaria Relative Risk (MRR) and crowding coefficient (Rc)

4.2.4.3 Antimalarial behavioral indicators have an effect on the absence of malaria

The variable describing utilization of mosquito bed nets as well as the EIG coefficient that mixes the regular cleaning of a house's surroundings, the utilization of indoor or outdoor insecticides and the utilization of grids on windows to protect from indoor mosquito biting appear to be important factors. However, the antimalarial predictive model related with prevention behaviour of the subjects has a very weak contribution to the prediction of malaria presence. On the other hand, this statistical model predicted very well the absence of malaria (see tab. 22). It therefore confirms the importance of prevention on malaria risks reduction strategies.

Mlogit model prediction of preventional factors

Malaria	**% of correct prediction**
No malaria ($rCPK_0$)	100.00%
Low malaria risk ($rCPK_1$)	0%
Middle malaria risk ($rCPK_2$)	0%
High malaria risk ($rCPK_3$)	0%
Malaria presence correct prediction (r_{mpp})	0.00%
Predicted malaria prevalence (P_{mP})	0%

Table 22: Statistical results of the preventional predictive model

Among MRR hot spots areas that show a low EIG coefficient are: Briqueterie (densely populated central areas), Soa, Simbok, and Mbankolo (peripheral rural patterns). The other districts concerned are: Mballa 1, Mballa 3, Mvog Betsi, parts of Melen, and Essos Nord (all central areas) (see fig. 66). This result suggests in the case of Briqueterie that absence of elements included in the EIG-coefficient (regular cleaning of surroundings, utilization of insecticides, and presence of mosquito nets on houses windows) contributes to the vulnerability of the population. Households with a low EIG coefficient tend to present a high malaria risk (see fig. 67). This figure reaffirms the importance of prevention as an antimalarial method. It particularly shows the importance of the elements that formed the EIG coefficient.

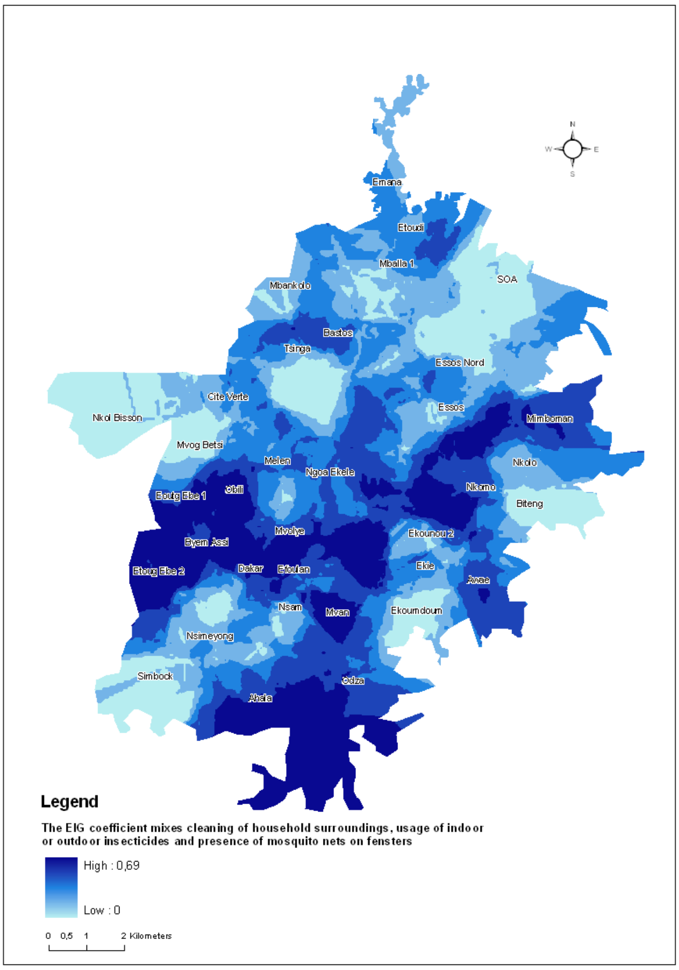


Figure 66: Spatial distribution of the EIG coefficient related with regular cleaning of household's surroundings, utilization of insecticides, and protective grids on windows

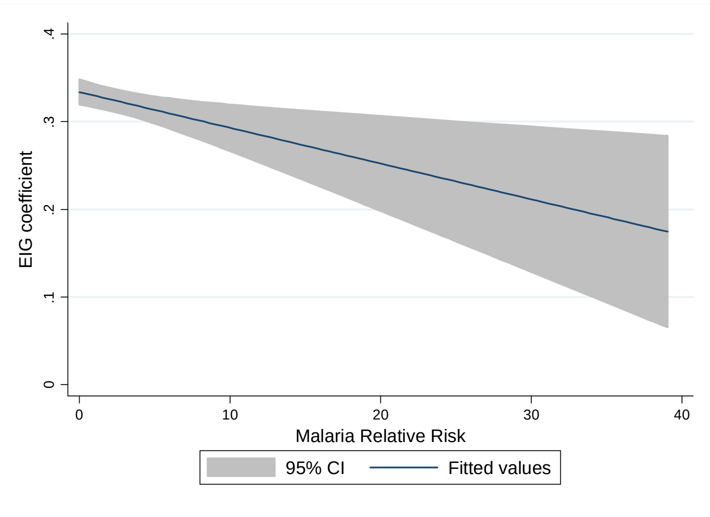


Figure 67: Fit between Malaria Relative Risk (MRR) and the. EIG coefficient related with regular cleaning of household's surroundings, utilization of insecticides and protective grids on windows

The distribution of areas that show a high level of people sleeping under non-treated mosquito nets reveals that MRR hot spots of Soa and Mbankolo (peripheral rural settings) and particularly Briqueterie (central densely populated) have a high number of persons sleeping under non-treated mosquito nets (see fig. 68). The relationship between the number of people sleeping under a mosquito net and MRR, although tending to be negative, is not linear (see fig.69).

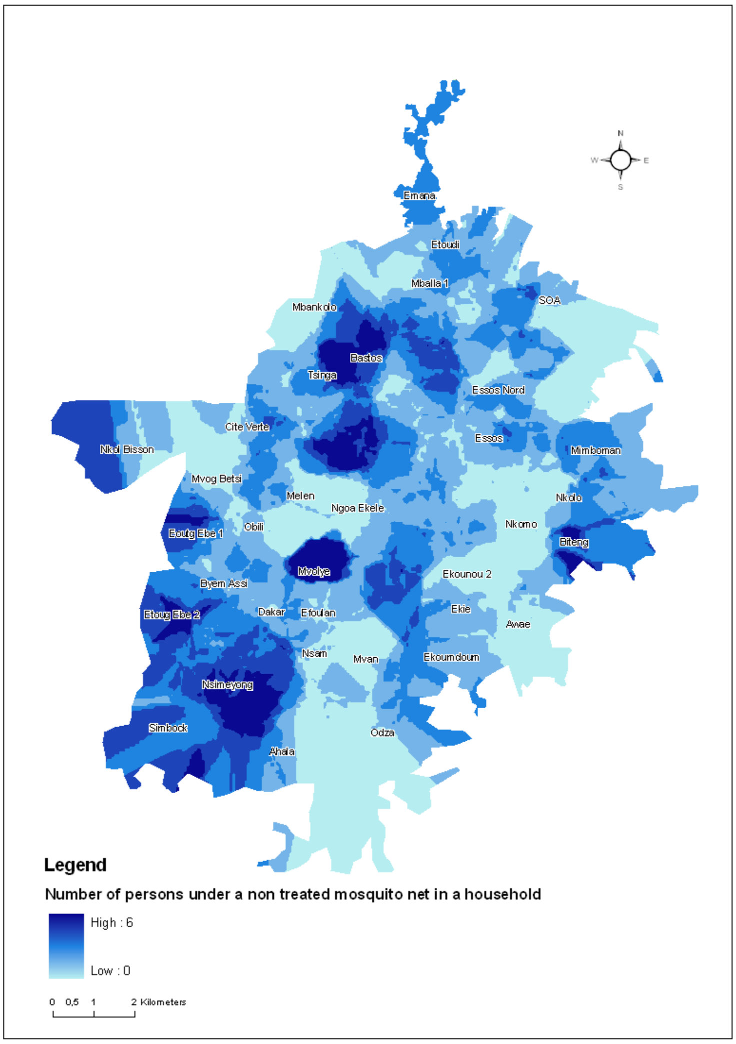


Figure 68: Spatial distribution of the number of people under non-treated mosquito nets

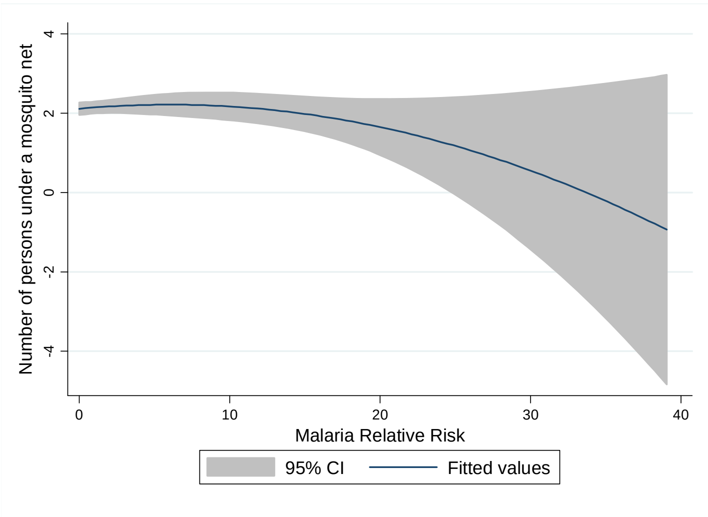


Figure 69: Fit between Malaria Relative Risk (MRR) and the number of people under a mosquito net

This result suggests various conclusions:

→ The high presence of non-treated mosquito nets is an indicator that confirms the high presence of malaria in these areas.

→ The mosquito nets do not have an effective action because of possible multiple causes that can be: their bad quality, their longevity (World Health Organization (WHO)) recommends changing a mosquito net at least every six months), and the fact that they are not treated. Thus, a high number of mosquito nets can exist, but with no effective effect on malaria.

4.2.5 A low predicted malaria prevalence rate

The overall predictive Mlogit-model gave a predicted household prevalence value of 9% while the observed household prevalence value was of 27%. The model correctly predicted 18% of the malaria cases and 76% of non-malaria cases (see tab. 23). The spatial expression of the Mlogit-model identified the hot spots of malaria, corresponding to the places where malaria was more frequently present (see fig. 70).

All the Mlogits models mixed together	**% of correct prediction**
No malaria correct prediction (Z_i, κ_0)	76.00%
Malaria presence correct prediction (Z_i, κ_1)	18.00%
Predicted malaria prevalence (P_{mP})	9.00%
Observed malaria prevalence	**27%**

Table 23: Statistical performance of the overall predictive model

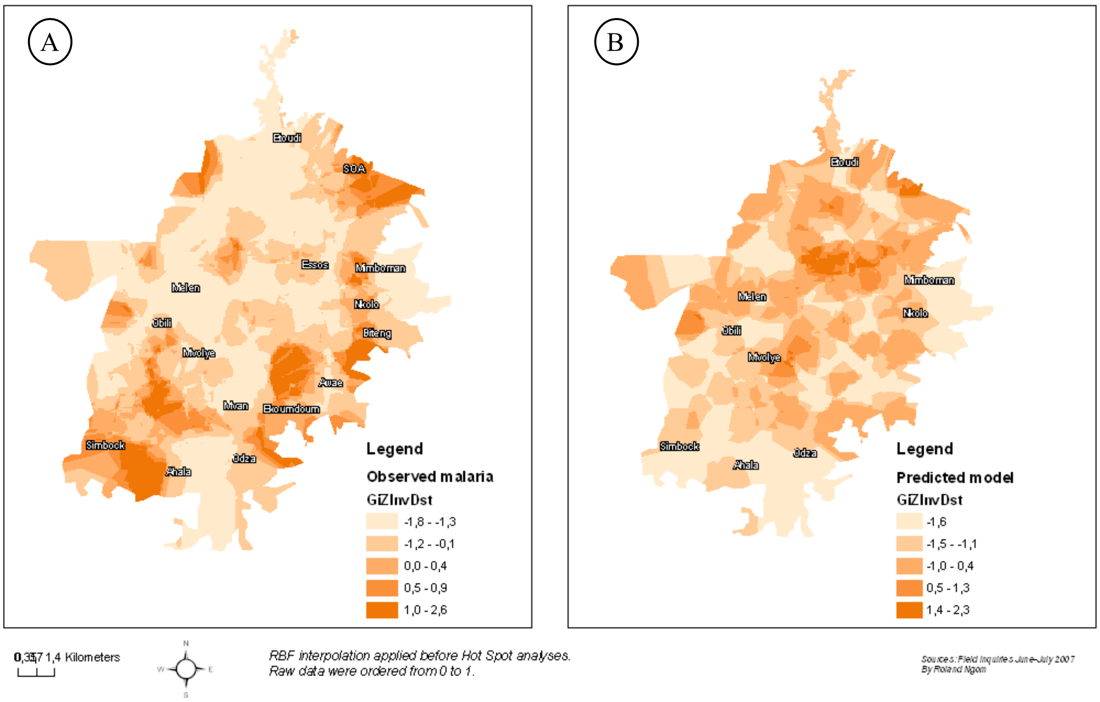


Figure 70: Comparison between the spatial representations of observed malaria (A) and the overall malaria predictive model (B)

4.3 Spatial structure of malaria in the morphological structure of Yaoundé

Key ecological and social variables have been identified in the statistical model as described in Chapter 4.2. The current chapter presents a spatial analysis of malaria in Yaoundé, based on both the information from the statistical model and those from the morphological structuring of the population. Detailed results on spatial demographic structures are presented, followed by an analysis of the probable relationship of this spatio-demographic profile with identified key variables associated with malaria. These analyses aim to construct a malarial knowedge-base that explains the spatial configuration of malaria in Yaoundé. This knowledge-base is further introduced into a Fuzzy-Logic model with the objective to predict malaria risks.

4.3.1 Central spatial distribution of the population

When considering the number of people per household, some households among the poorest and the intermediate people show a very high number of inhabitants (see fig. 71). These outliers are weighted when considering the mean number of people within each economic category. In addition, the comparison of standard deviations of numbers of persons per household between various economic categories shows any significant difference. The result for all the categories together states that the mean number of inhabitants per household in the city is equal to 5.

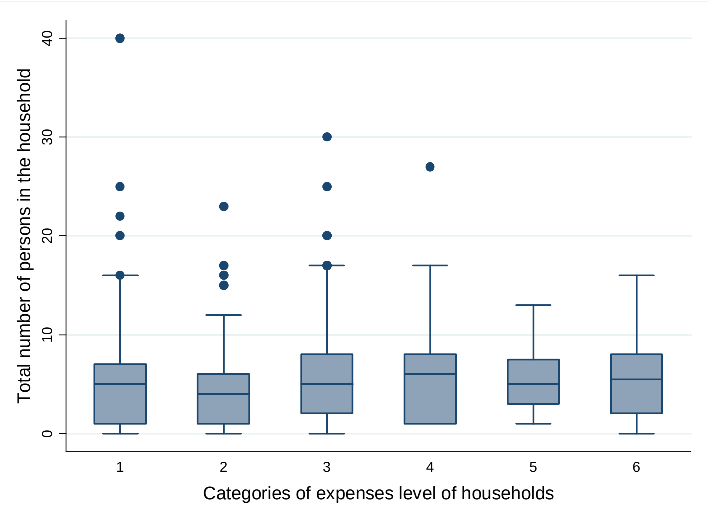


Figure 71: Categories of households' expenses as social indicator of the total number of persons in households

The results of the comparison of the demographical estimates (from QuickBird) of three surveys of settlements standards: high standing (X_1), densely populated (X_2) and peripheral rural (X_3), logically showed differences in population densities. The ratio of soil-occupation by the buildings (households) in the densely populated PA was 72% against 19% for the high standard planned survey PA and only 10% for the rural PA. The mean household surface values of the three PA logically illustrated their differences in population densities. They are 64 m^2, 69 m^2 and 94 m^2, respectively for X_1, X_2, and X_3 PA. The mean household surface $\overline{S_{B,\,Yaoundé}}$ for the three surveys was 74 m^2, while the mean household value of the total surface $\overline{S_{B}'}_{,\,Yaoundé}$ is 80 m^2. These results illustrate the morphological proximity between high standing areas and peripheral rural areas. The habitat is very sparsely distributed in peripheral areas, which could impact on transmissions risks. The high standing areas show a less sparsely distributed habitat pattern. The densely populated areas logically show a very compact pattern, hardly giving any space for ecological features such as vegetation.

The estimation of the total population, $P,_{Yaoundé}$ from QuickBird data, gives a total of 2,218,000 inhabitants. The results of the calculation of the districts density, $DS,_{districts}$ show a centrally oriented spatial distribution of the population (see fig. 72). The highest population densities (between 31 and 50 inhabitants per km^2) are mostly found in the oldest urban nucleus. All correspond to non-planned areas: Briqueterie, Nkomkana, Madagascar, Mvog Ada, Nkolndongo, Mokolo, Tsinga, Madasgascar, Elig-Edzoa. Less old but non planned areas are also identifiables: Obili, Ekounou, Mballa 4, and Mballa 3. What is also remarkable is the belt shaped distribution of the lowest densities at the peripheries of the city. However, some centralized districts such as Mballa 2, Olezoa, and Mvolye also show low densities.

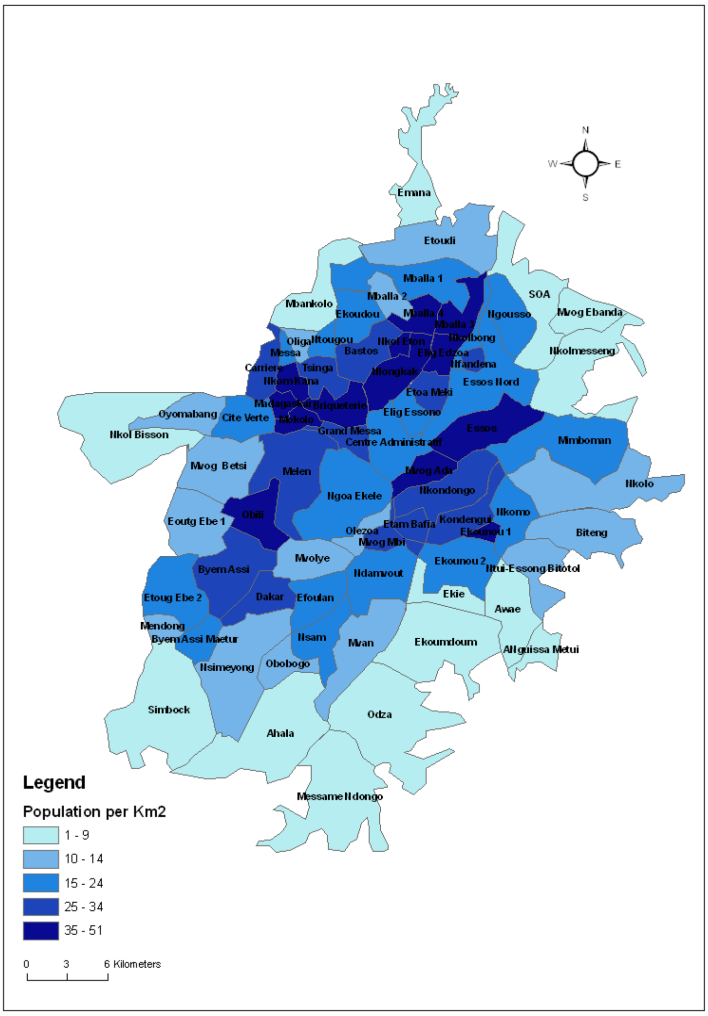


Figure 72: Districts-based population densities

The spatial distribution of districts population densities $DS,_{districts}$ is symmetric to that of the IU (see fig. 73). It confirms that settlement of population is influenced by the presence of administrative and domestic commodities, as well as by the presence of opportunities for economic (informal) activities. An estimation of the distribution of the population according to the various PA patterns (see tab. 24), shows that extremely dense PA have the highest rate of spatial presence. They consequently have the highest estimated number of people (37%). They are followed by the class intermediate II (41 to 700 estimated households), which host 24% of the total human population of the city. With an estimated population presence rate of 14%, the class intermediate I have the lowest spatial coverage. Extremely isolated and isolated PA host 18% of the city's total population, despite the fact that they represent the majority of the present spatial objects.

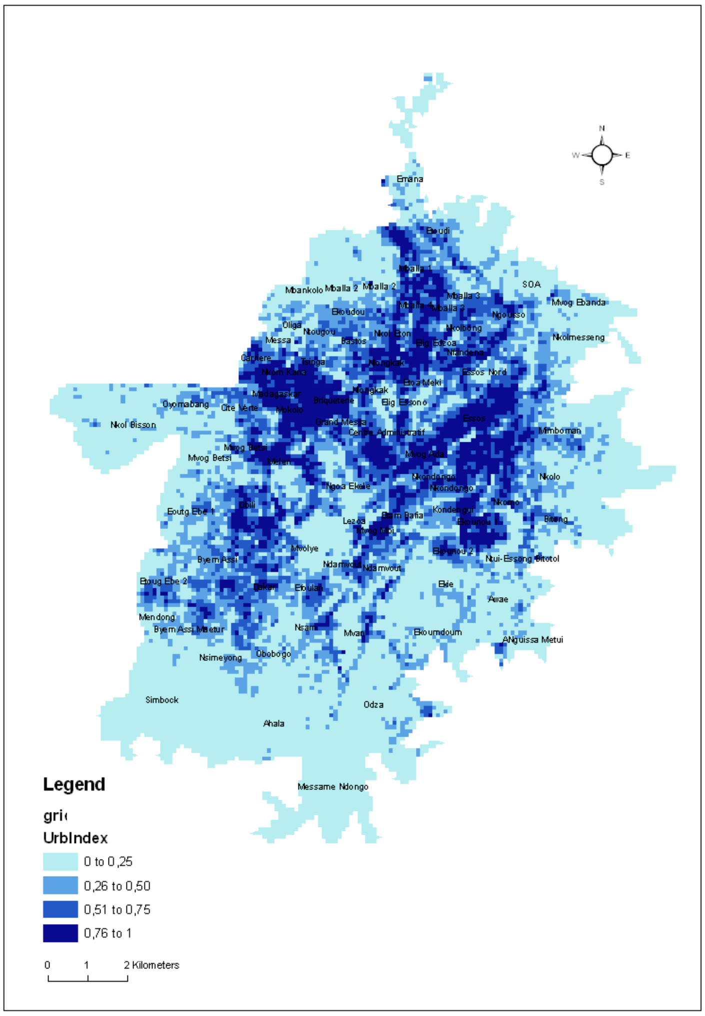


Figure 73: Spatial representation of the Index of Urbanity (IU)

	Population aggregates (PA)	Estimated number of houses/buildings	% of total spatial objects (polygons)	% of estimated number of people
1	Extremely isolated	<=1 (in accordance with the mean surface of a household)	45.36%	16%
2	Isolated	2-10	44.23%	2%
3	Intermediate I	11-40	7.04%	14%
4	Intermediate II	41-700	2.93%	24 %
5	Very dense	701-2000	0.074%	7%
6	Extremely dense	>2000	0.033%	37%7

Table 24: Spatial and demographical characteristics of the population aggregates (PA)

The extremely dense PA almost all correspond to the oldest urban nucleus of the city. The one present in the south west side of the city makes an exception; it comprises more recently occupied areas. It notably includes the districts of Biyem-Assi and Obili. Many of the extremely isolated and isolated PA are found in the peri-urban areas of the city. The southern part of the city is particularly sparsely inhabited. However, extremely isolated and isolated PA are also visible in the central part of the city (see fig. 74 and fig.75).

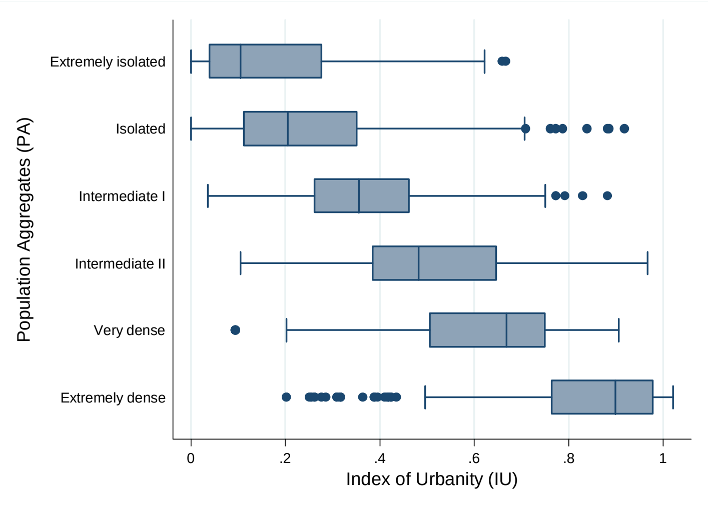


Figure 74: Comparison of the Index of Urbanity (IU) by population aggregates (PA)

The spatial structure of PA is also visible within the IU-map (see fig. 75). In fact, the spatial distribution of the IU is symmetric to that of households and population PA (see fig. 76). The correlation between the IU and the various categories of PA logically shows a very high, positive and significant relationship in the case of extremely dense PA (R=0.75 significant at CI=99%). This correlation is also positive and significant in the case of very dense PA (CI=99% and R= 0.08). On the contrary, the correlations with extremely isolated, isolated and intermediate I classes are significant and negative (all at CI=99%). The intermediate I pattern has no significant correlation with IU. This diagram confirms that the population that is living in the densest zones is mostly found in central urbanized areas of the city (see fig. 72, fig. 73, and fig. 74). The diagram of the spatial distribution of households from field surveys also illustrates the dichotomy between isolated and denser PA (see fig. 76).

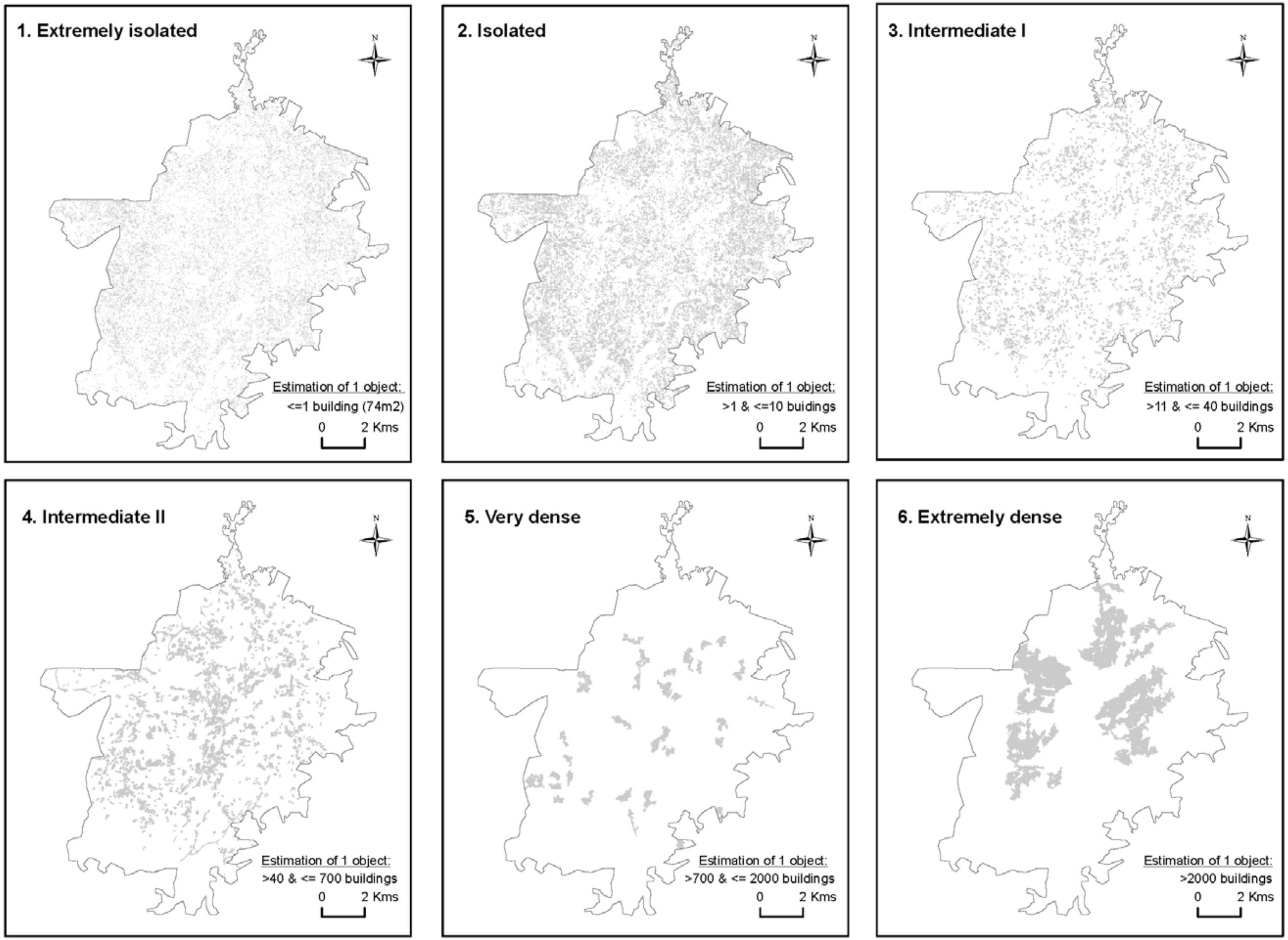


Figure 75: Population aggregates (PA)

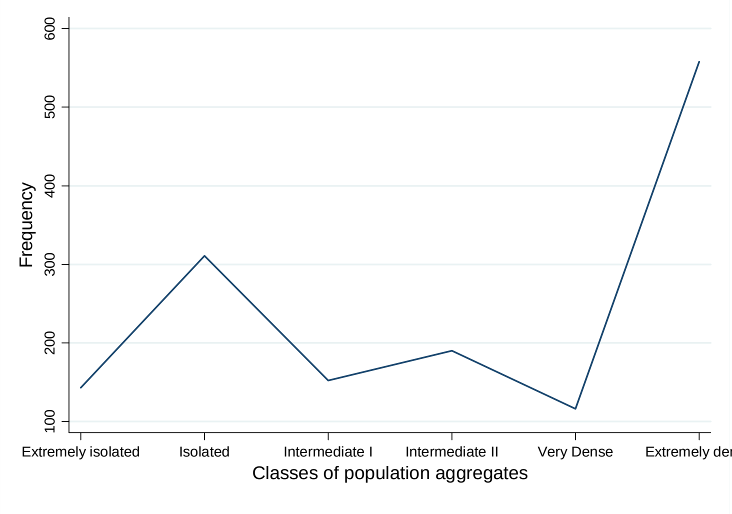


Figure 76: Distribution of the households from field survey according to populations aggregates (PA)

4.3.2 Malaria prevalence in population aggregates (PA)

The distribution of mean Malaria Relative Risk (MRR) values resulting from the direct spatial extractions of the whole map of PA (not from households' field surveys), shows a linear progression of MRR from the most isolated to the densest PA (see fig. 77). It suggests that -

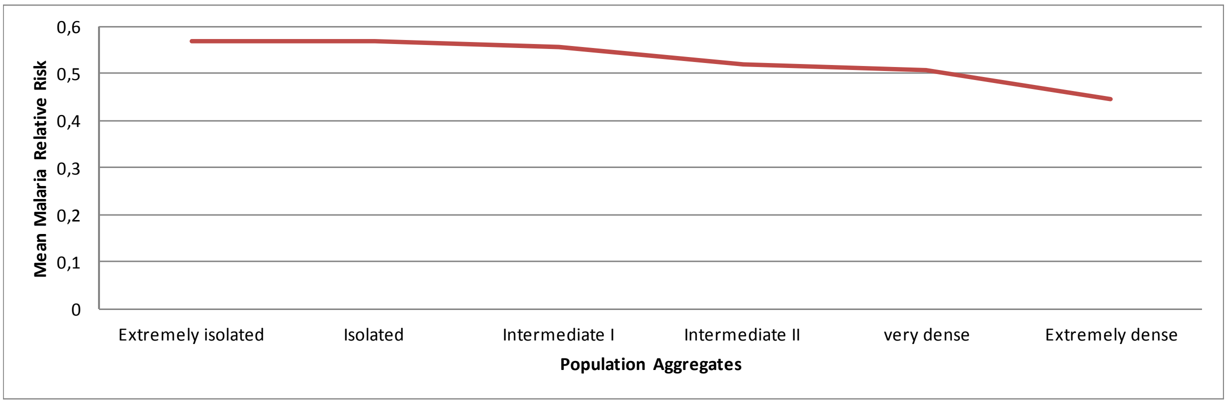


Figure 77: Mean values of Malaria Relative Risk (MRR) according to various population aggregates (PA)

malaria prevalence is higher in isolated PA. It also means that despite the presence of some MRR hot spots in central urban areas, malaria prevalence is declining according to the degree of urbanity (see fig. 77). This pattern is biased when households from field surveys are considered (see fig. 78 and table 25).

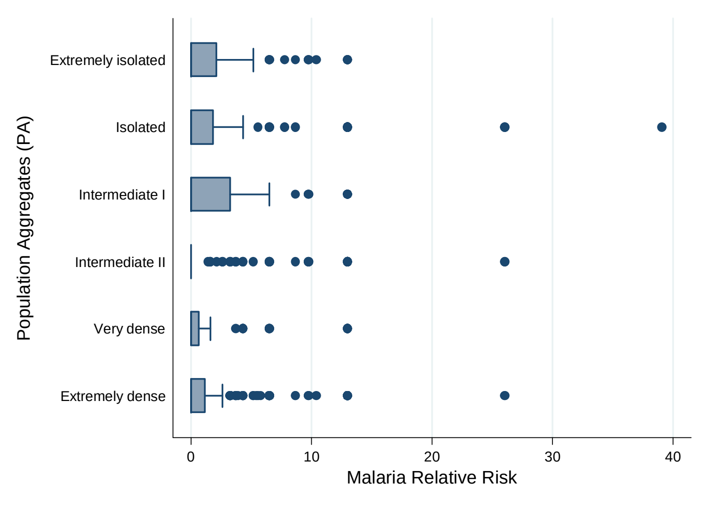


Figure 78: Malaria Relative Risk (MRR) according to population aggregates (PA) from the household field survey

Despite the fact that malaria is prevalent within extremely isolated, isolated very dense, and extremely dense PA, only its relationship with the intermediate I PA is significant (positive at 95% confidence intervals with R = 0.07). Household-based malaria presence ratios stress the importance of intermediate I-classes (see fig. 79).

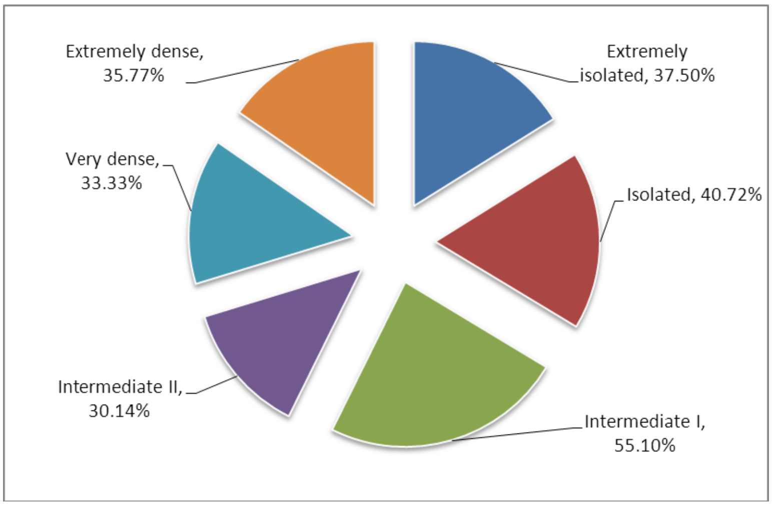


Figure 79: Ratios of malaria presence for various categories of population aggregates (PA)

This indicator also shows that malaria is important in isolated and extremely isolated classes. Malaria presence ratio is slightly much higher in extremely dense PA than in very dense and intermediate II PA. Consequently, intermediate I and isolated PA are experiencing the highest number of malaria episodes. People in the extremely isolated PA also experienced multiple malaria episodes during the same year, but less than those in isolated and intermediate I PA (see fig. 79)

The relationship between MRR and IU is negative (see fig. 80). This result is in line with the diagram of the relationship between MRR and the PA. It shows that malaria prevalence is diminishing according to the highest level of urbanization (see fig. 80).

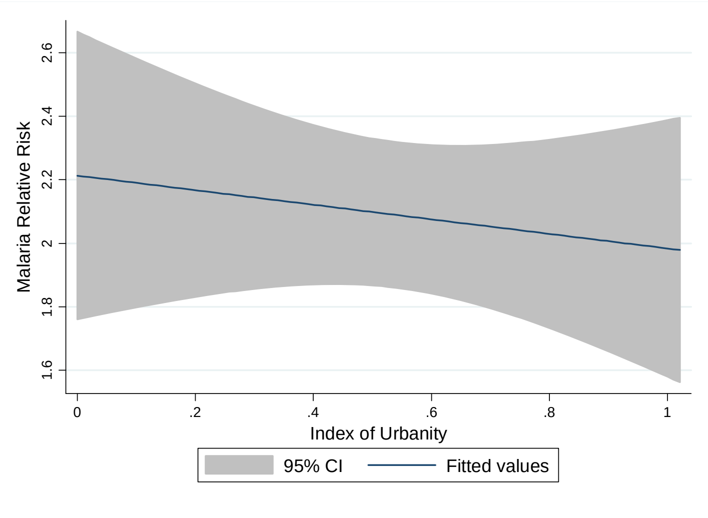


Figure 80: Fit between Malaria Relative Risk (MRR) and the index of urbanity (IU)

When statistically assessing the seasonal relationships of MRR with the IU, it is evident that malaria during the small rainy season is not prevalent in most urbanized areas. The correlations between the IU and various seasonal outputs of MRR, show a positive and significant relationship with the big rainy season (CI=95% and R=0. 03). The relationship of the IU with the MRR during the small rainy season, which is malaria's more prevalent season, is also significant (CI=99% R=0.08), but negative. Moreover, extremely dense PA also show a negative and significant association with the MRR in the small rainy season (CI=99% R=0.10). The poor contribution of extremely dense PA to malaria prevalence during the small rainy season is also illustrated by its lowest household-based ratio of malaria presence (see tab. 26). However, the contribution of these PA to malaria prevalence becomes very important during the big dry- and the big rainy seasons (see fig.79). The relationship of extremely dense PA with these seasons is positive and significant at CI=99%.

Only isolated and intermediate I PA have a significant correlation with the MRR during the small rainy season. These relationships are both positive (respectively with CI=95 % and CI=99%). Their contribution to the MRR during this season is also visible in their household-based ratio of malaria presence (see tab. 25). The intermediate II PA have negative and significant correlations with both big rainy- and dry seasons (both at CI=95%). Malaria is more prevalent in these PA during the small rainy season (see tab. 27). The only significant relationship of very dense PA with seasonal MRR is during the big rainy season (CI=99% and R=0.05). They are the PA that have the highest household-based ratio of malaria presence during this season. Despite the fact that the contribution of extremely isolated PA is more important during the small rainy season, they have no significant relationship with any of the MRR seasonal outcomes.

These results are in line with the visual observations made from the seasonal maps of MRR. They suggest that malaria natural ecological factors, notably rainfall, have a more direct impact on malaria-transmission in less urbanized areas (less densely populated PA). These results also suggest that less urbanized areas are ecologically more suitable for the development of the malaria natural cycle. This assumption is made on the basis of entomological studies on Yaoundé (see Chapter 2.5.1.3). However, only the exploration of the relationship between a population's PA and other intervening key factors will allow a better understanding of the malaria morphological patterns.

Population aggregates (PA)	Household-based malaria presence ratios for the small dry season	Household-based malaria presence ratios for the big rainy season	Household-based malaria presence ratios for the big dry season	Household-based malaria presence ratios for the small rainy season
Extremely isolated	6.72%	7.52%	6.16%	17.21%
Isolated	2.98%	8.74%	7.12%	18.25%
Intermediate I	6.29%	10.14%	6.29%	27.73%
Intermediate II	3.26%	4.97%	6.74%	16.56%
Very dense	9.43%	0.87%	7.62%	13.73%
Extremely dense	4.10%	11.60%	7.18%	8.77%
The entire city	4.63%	8.65%	7.28%	14.66%

Table 25: Household-based ratios of seasonal malaria

4.3.3 Population aggregates (PA) and urban agriculture (UA)

The largest part of the population in the most urbanized areas (the densely populated), are not found in valleys (see fig. 81 and fig. 82). This distribution could be explained by the fact that they are the most numerous in a hilly environment. The highest elevation values are found in extremely dense PA (see fig. 81). This PA is also the only one that is positively and significantly associated with elevation values (CI=99%, R=0,17). People in the extremely isolated PA are more significantly installed in valleys. This is possibly related with agricultural activities. The other PA but the very dense PA, show a negative association with elevation values.

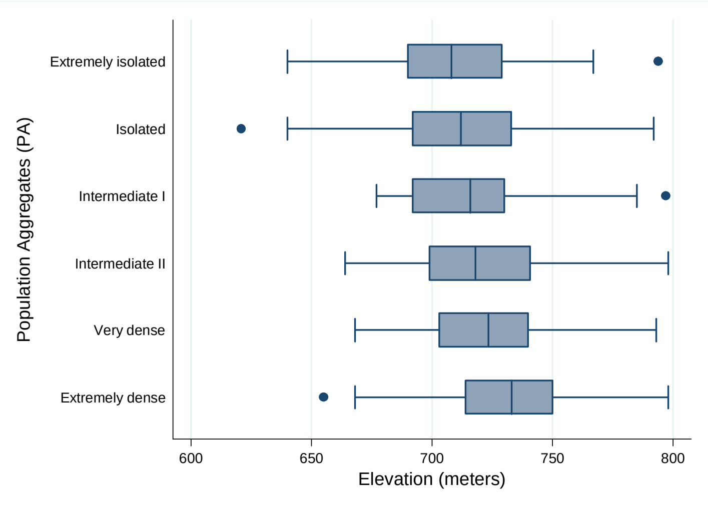


Figure 81: Distribution of population aggregates (PA) according to elevation values

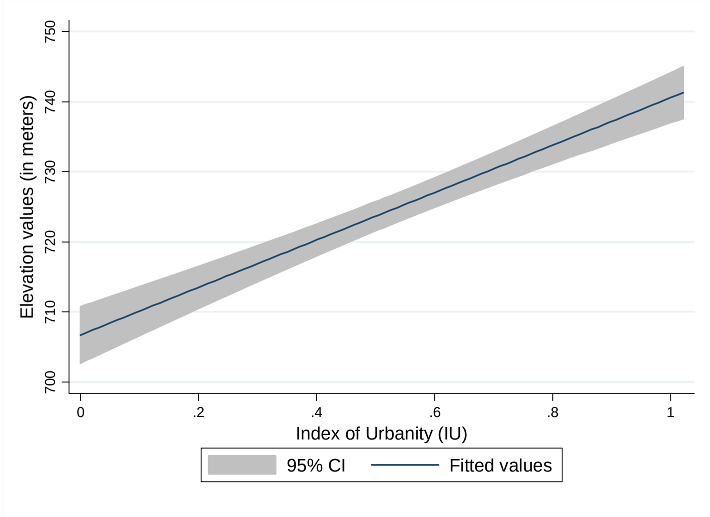


Figure 82: Fit between elevation values and index of urbanity (IU)

With a mean distance of 452 meters, households in extremely isolated PA are the closest to agricultural areas (see fig. 97). They have the highest significant correlation value with distance to agricultural areas (CI= 99%, R = -0.14). Intermediate I PA are closer to agricultural zones (a mean distance of 540 meters) than isolated PA (a mean distance of 590 meters). They are both negatively correlated with distance to agricultural zones. The very dense PA are very distant to agricultural areas (a mean distance of 821 meters). Their correlation is high, positive and significant at 99% confidence intervals. The correlation of extremely dense PA with the distance to agricultural areas is also positive and significant at 99% confidence intervals with a correlation value higher than that between very dense PA and the distance to agricultural zones. But they are far more close to agricultural areas than very dense PA (a mean of distance of 743 meters). The intermediate II category has no significant relationship with the distance to agricultural patterns. Households from densely populated PA are the less distant to water bodies (see fig. 83). This proximity is an opportunity for the poor population to be involved in agricultural activities.

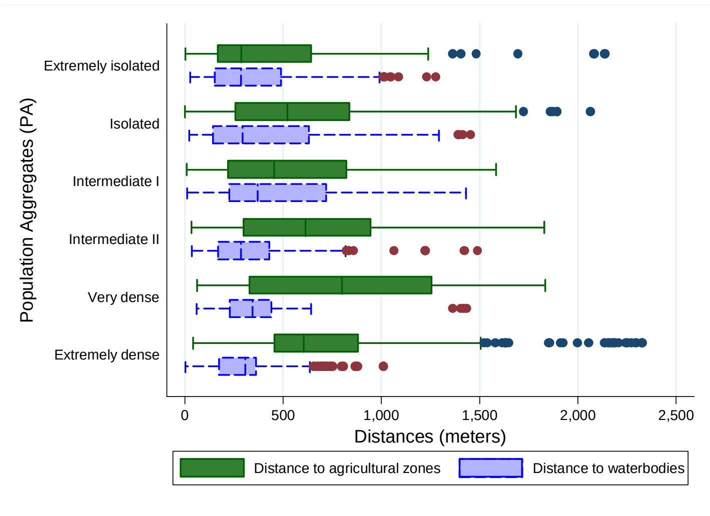


Figure 83: Distances of population aggregates (PA) to farming areas and water bodies

This structure is validated by the ratios of people actively involved in agricultural activities. These ratios state that people are actively practicing agricultural activities in isolated and extremely isolated PA (see tab. 26). The ratio of the intermediate I PA is also higher than the ratio of the entire city. One can note that people are involved in agricultural activities in extremely dense PA. Significant information is the absence of actors in the agricultural sector within very dense PA.

Population aggregates (PA)	Ratios of people actively involved in agricultural activities
Extremely isolated	7.69%
Isolated	13.55%
Intermediate I	5.63%
Intermediate II	3.15%
Very dense	0%
Extremely dense	2.02%
The entire city	4.91%

Table 26: Ratios of people involved in agricultural activities within various population aggregates (PA)

4.3.4 Population aggregates (PA) and Economic Capacity (EC)

Households in extremely dense PA have the lowest Economic Capacity (EC). Their correlation with the EC is negative and significant. They are the only PA that have a negative correlation with the EC. Extremely dense PA are characterized by a massive presence of poor people (see fig. 84). Households in very dense PA have the highest EC. They are not so distant to intermediate I and intermediate II PA. They all have a positive correlation with the EC. However, this correlation is not significant in the case of intermediate I PA. The relationship of extremely isolated PA with the EC is also not significant.

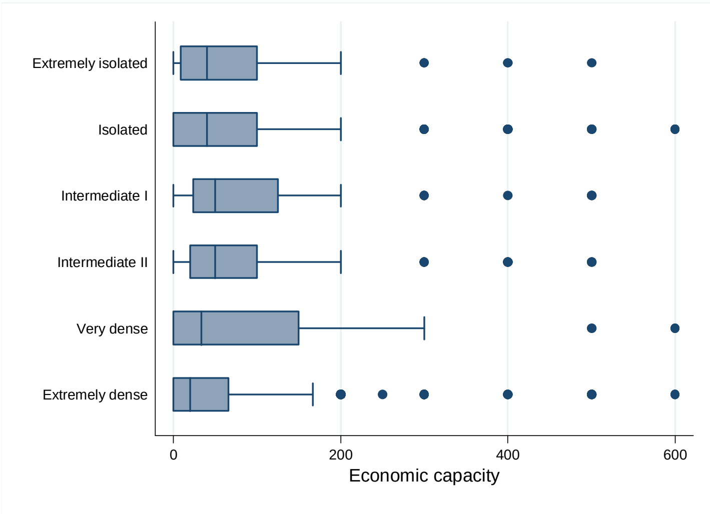


Figure 84: Economic Capacity (EC) by population aggregates (PA)

In general, the more people are living in highly urbanized areas, the less rich they are (see fig. 85). This diagram is plausible since very dense PA represent a very small part of the population (only 7%) and the extremely dense PA the largest part (37%). Economic poverty is definitively not a rural characteristic (in the sense of the IU); on the contrary, areas with a rural pattern are drawing an acceptable EC-level.

The employment structure also designs the insecure economic situation of peoples living in extremely dense PA. The highest ratio of people employed in informal activities is found in those PA (see tab. 27). Here is also logically found the lowest ratio of public servant and people involved in liberal activities (lawyers, bailiffs etc.). The ratio of people involved in liberal activities is very high for the very dense PA, which could explain the high value of EC of these PA. Also interesting is the important presence (higher than the ratio of the entire city) of liberal activities in rural extremely isolated PA. The correlation between informal activities and households in extremely dense population PA is positive and significant at 95% confidence intervals. This correlation is negative and significant with both Isolated and intermediate PA.

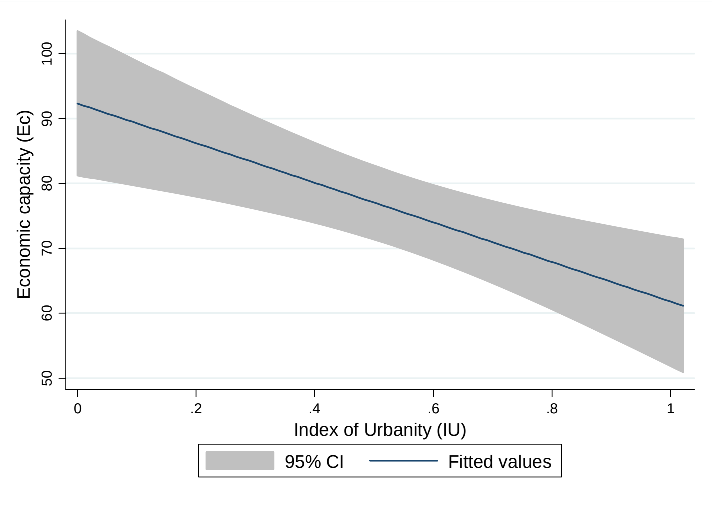


Figure 85: Fit between the Economic Capacity (EC) and the Index of Urbanity (IU)

Population aggregates (PA)	Ratios of people employed in informal activities	Ratios of people employed in the public sector	Ratios of people employed in liberal activities
Extremely isolated	93.10%	47.36%	14.28%
Isolated	88.73%	41.05%	13.55%
Intermediate I	92.30%	47.05%	17.18%
Intermediate II	84.90%	63.33%	13.95%
Very dense	85.71%	34.48%	39.28%
Extremely dense	350.74%	17.05%	5.96%
The entire ty	151.42%	32.58%	11.74%

Table 27: Ratios of some employment categories by population aggregates (PA)

4.3.5 Population aggregates (PA) and Crowding

Extremely dense PA have the highest crowding coefficients (3.69); they are followed by the extremely isolated PA (3.24) (see fig. 86). However, the relationship is positive and significant only in the case of extremely dense PA (CICI=99% , R=0.17). This relationship is not significant in the case of extremely isolated PA. The crowding coefficient is also high for isolated PA, but the two variables are negatively and significantly correlated (CI=99% CI, R=0.06). Negative and significant are also the correlations of crowding coefficient with both Intermediate I and II PA. Those two PA have a similar crowding coefficient (2.74 and 2.78). The lowest crowding coefficient value is that of very dense PA (2.71). This last PA also draws negative and significant correlations with the crowding coefficient (CI=95% CI, R=0.05). This scheme is confirmed by that of the fit between the crowding coefficient and the Index of Urbanity (see fig. 87).

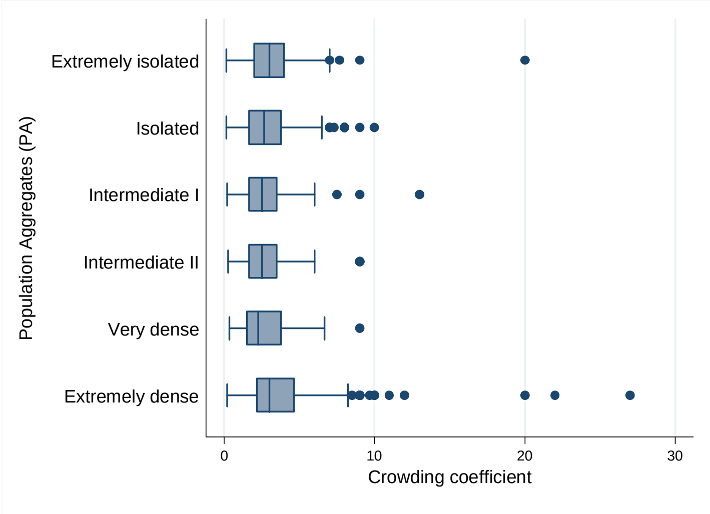


Figure 86: Crowding coefficient by population aggregates (PA)

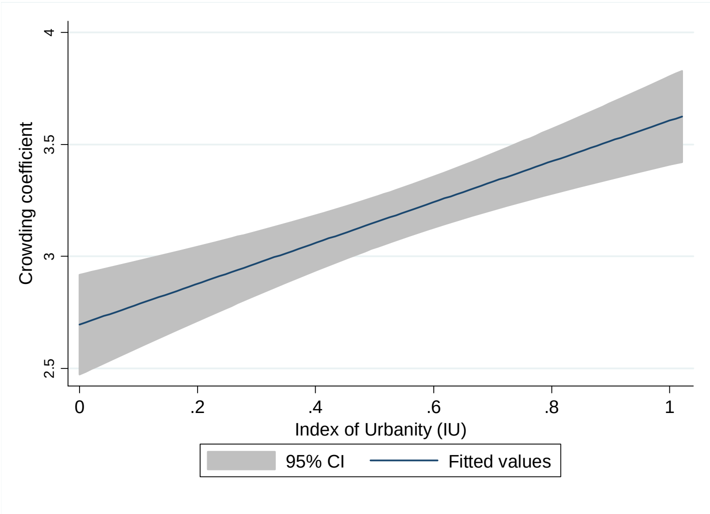


Figure 87: Fit between crowding coefficient and Index of Urbanity (IU)

The importance of the crowding coefficient in extremely dense PA is also illustrated by the IU. The room crowding coefficient which is the crowding factor that contributes the most to MRR has a significant correlation only with extremely dense and Intermediate II PA. This relation is positive (CI=99%, R=0.12) in the case of extremely dense PA and negative with Intermediate II PA (CI=99%, R=0.04). The Room crowding relationship with the IU is similar to that of the total crowding coefficient with the same IU (see fig. 87 and fig. 88).

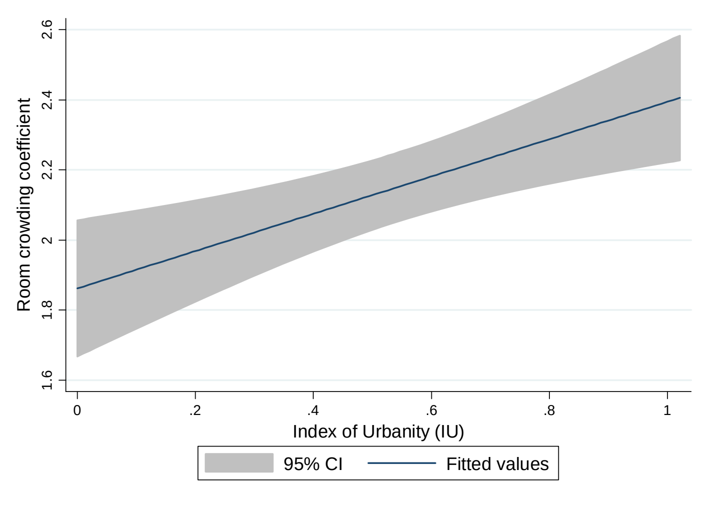


Figure 88: Fit between Room crowding (Rc) and the Index of Urbanity (IU)

When analysing the characteristics of the other factors involved in the general crowding coefficient, one can note that extremely isolated PA are distinguishing themselves by having the highest values (see tab. 28). They have a very high ratio of external toilets, which is an important MRR-predictive factor. The relationship of extremely isolated PA with this factor is positive and significant (CI=99%, R=0.06). The correlation with external toilets is also positive and significant in the case of extremely dense PA (CI=99%, R=0.06). The Intermediate II and very dense PA draw a significant but negative correlation with the variable external toilets. This relationship is not significant in the case of isolated and Intermediate I categories. For all these crowding related variables, the very dense PA have the lowest values, which suggest they are the less crowded.

Population aggregates (PA)	Ratios of external toilets	Ratios of presence of gaps on walls
Extremely isolated	266.67%	41.58%
Isolated	146.83%	39.64%
Intermediate I	176.36%	31.03%
Intermediate II	108.79%	31.94%
Very dense	84.13%	14.85%
Extremely dense	190.63%	49.20%
The entire city	159.71%	38.84%

Table 28: Ratios of presence for some crowding-related variables

4.3.6 Population aggregates (PA) and malaria prevention

The lowest prevention coefficients are found in the intermediate I and extremely dense PA (see fig. 89). However only extremely dense PA have a significant relationship with the prevention coefficient (CI=99%, R=0.11). The relation is also negative and significant (CI=99%, R=0.06), between extremely dense PA and the number of persons under a mosquito net, which is one of the malaria's important predictive variables. The scheme is the same (negative with CI=99%, R=0.23) between extremely dense PA and the EIG-coefficient (indicates the regular cleaning of household's surrounding environment, the utilization of insecticides and the presence of protective grids on windows). The low contribution of extremely dense PA to the EIG-coefficient is notably illustrated by its lowest ratio of households regularly cleaning their surrounding environment. In conclusion, the extremely dense PA only draw negative relationships with preventive variables. These negative relationships are illustrated by the negative direction of the shape of the diagram showing the fit between prevention coefficient and the IU (see fig. 90).

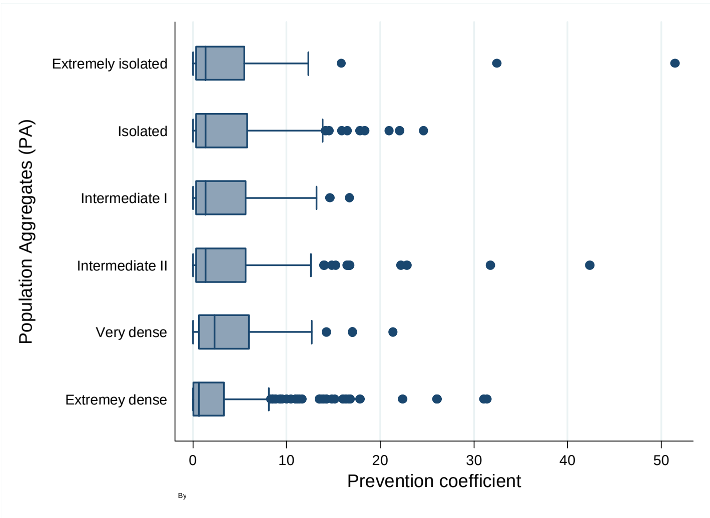


Figure 89: Prevention coefficient by population aggregates (PA)

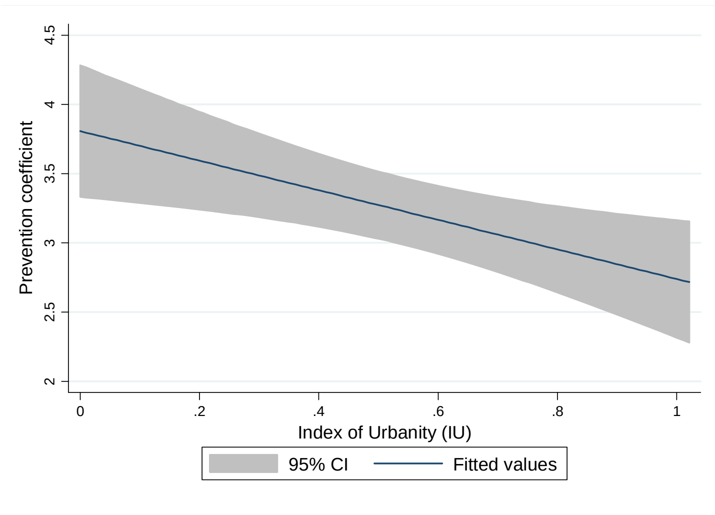


Figure 90: Fit between the prevention coefficient and Index of Urbanity (IU)

Very dense PA are drawing positive and significant relationships with both the prevention coefficient (CI= 99%, R= 0.06) and the number of persons under mosquito nets (CI=99%, R= 0.05). They bear the highest preventive values (see fig. 91 and tab. 29). They are closely followed by the intermediate II PA. But these last PA only have a significant relationship with the EIG-coefficient (CI=99% CI, R=0.09).

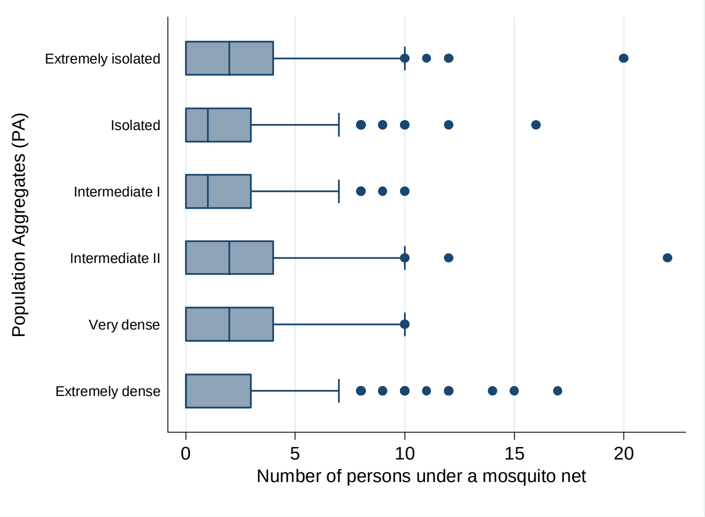


Figure 91: Number of persons under a mosquito net by population aggregates

Intermediate I PA have no significant correlation with any of the important prevention variables (in a malaria prediction point of view, and when relating to the developed statistical models). The isolated PA's unique significant relationship with those variables is with the EIG coefficient (CI=99%, R=0.08).

Population aggregates (PA)	**Ratio of presence of grids on windows**	**Ratio of people regularly cleaning their environment**
Extremely isolated	8.33%	155.36%
Isolated	12.68%	108.72%
Intermediate I	14.29%	76.74%
Intermediate II	18.01%	102.13%
Very dense	20.83%	75.76%
Extremely dense	12.73%	50.00%
Total	13.69%	78.61%

Table 29: Some antimalarial prevention indicators

4.3.7 The meaning of morphological segmentation to malaria and its socio-ecologic correlates

4.3.7.1 Identified effect of the population density

Since malaria vectors will, in general, look for hosts at the nearest place to their ecological niche, there are good chances that they regularly fly in the direction of the nearest PA, or within the same PA (GITHEKO et al., 1996; STAEDKE et al., 2003; KAUFMANN & BRIEGEL, 2004). In a very simple basic logic, the number of malaria cases will be dependent on the number of available hosts in that PA. Following this logic and excluding other intervening factors, it can be said that the spatial segregation of the population into various PA is contributing to the identification of the basic demographical prerequisites for a malaria-transmission processes to exist in any given sub-area of the city.

The size of a PA is proportional to the degree of isolation of its houses/buildings. The more isolated a house in a given PA is, the more chances it has to be surrounded by suitable malaria- natural ecological factors such as vegetation. Vegetation features have various forms. In the present case, the suitability of vegetation to malaria is found in UA areas. This relationship is illustrated by the distribution of the IU by various PA (see fig. 90). On the basis of this assumption it can be affirmed that less densely populated PA are the most exposed to malaria risks when considering the intervention of natural ecological variables.

High population densities (bigger and denser PA) can have a reverse effect on an effective malaria-transmission; they can be a limiting factor to the malaria-transmission sustainability (CHINERY, 1984; SABATINELLI, et al. 1986; PROTHERO, 1989, MARTENS & HALL, 2000). In fact, the effectiveness and the intensity of this transmission will depend on the ecological needs of the vector for its development. The most dangerous malaria vectors species (section 9.3) need natural stable ecological *nidus* for their biological development. When the densities are too high, these conditions are not easily fulfilled. Following this reasoning, areas having a very high density offer almost no place for natural ecological favourable features. When these conditions are offered within a dense PA, they are often logically very perturbed. The question is to know which levels of population-densification are suitable to such non-favourable conditions. The segregation procedure is an attempt to give an answer to this question. By defining plausible thresholds, results of the segregation give the opportunity to identify such kind of areas. Extremely dense PAs correspond to this category of areas. Although having the highest number of potential human hosts, they do not necessarily have the highest number of malaria cases. This conclusion is made in the exclusion of the potential intervening social variables; it only considers the basic general demographical effect of PA.

The intermediate I PA corresponds to the most demographically suitable sites for a significant malaria-transmission process to be present. They are neither too dense nor too small. They draw malaria transmission suitability according to these demographical charactheristics. These charactheristics will vary according to two different tendencies: one in the direction of extremely dense PA demographical characteristics, another in the direction of extremely isolated PA demographic characteristics. However, the degree of malaria-transmission-risk within these intermediate PA will depend on other various key factors.

4.3.7.2 Socio-malarial distinction between urban and peri-urban patterns

In the case of Yaoundé, the demographical effect is associated with a particular socio-spatial context. The most densely populated PA have a central geographic situation; it means that they are not found in peripheral or peri-urban areas of the administrative boundaries of Yaoundé. This fact is an additional non-favourable factor to an intensive malaria-transmission process, simply because central areas are the most urbanized (according to the IU). Central areas are fatally those where chances to find extended natural factors are the lowest. One should keep in mind that the city is extending at the expense of former rural areas. This extension has a central origin; it globally corresponds to the Von-Thünen theory (VON THÜNEN, 1850). Rural economic activities such as agriculture are more developed in peri-urban areas, but not exclusively. Actual results show that agriculture is present as an economic activity within central extremely dense PA.

This finding is sensible when regarding the macro and international economic conditions. The non-informal sector employment rate is very low. The difficult economic climate has lowered prices of extended rurally cultivated colonial products, such as cocoa. A considerable part of the cultivated soils from the forest zone have been depleted, but rural areas did not benefit by some basic developmental infrastructures. All this resulted in a frenetic rural exodus, which significantly contributed to the increase in the unemployment rate in Yaoundé. The largest part of these unemployed are located within extremely dense areas, where they are dealing with informal activities (JOYGNY-GRUPP, 1988; MATHIEU & TABUTIN, 1996; KENGNE & MOUGOUE 1997; CHEN et al., 1998; ADEPOJU, 2000; POTTS, 2000; DE JONG & KENGNE, 2002; KENGNE, 2004). Peasants in the very peri-urban fringes of the city (formerly rural) just converted their agricultural activities into economically most adapted ones. They stopped cultivating cocoa, palm oil, and invested in more marketable and sustainable products and activities, such as lettuces production, fish farming (NJOM, 1999; ENDAMANA et al., 2000; MBAZO'O et al., 2000; ENDAMANA et al., 2001). A large part of migrants from rural zones also invested in agricultural activities for both commercial and subsistence purposes (RABINOVITCH & SCHMETZER, 1997; STREIFFELER, 2000, MBAZO'O et al., 2000). These agricultural activities are theoretically very highly associated with malaria presence in both extremely dense and extremely isolated PA.

This transfer of rural cultural patterns is also visible in crowding indicators of the extremely dense PA (see fig 92). The ratios of gaps on walls and the ratios of houses with opened windows are the highest in extremely dense and extremely isolated PA. The geographic proximity to rural areas and high crowding coefficient of extremely isolated areas and its lowest IU, clearly indicate the presence of rural patterns. This high crowding coefficient of the identified PA theoretically expose them to a higher malaria transmission risk.

The very high crowding coefficient as well as the very low EC of extremely dense PA indicate that they globally correspond to slums in non-planned areas. This low EC is theoretically symmetric to the low prevention coefficient that is drawn by people in extremely dense PA. On the other hand, extremely isolated PA have a higher EC than extremely dense PA. This could be partly explained by the assessment of land. Land has become unavailable and very expensive in most urbanized areas. On the other hand, land is still available at a lower cost in more rural peri-urban areas. People who are buying land in those areas are those who have enough money to do so. People who have enough financial resources to assure their transportation from these places to the place of their job (that is, by the way, often centrally situated) are also concerned. It implies that concerned people have a better social situation. The high presence of civil servants and people employed in liberal activities are a testimony of the presence of such kind of people in those areas. One should know that because of corruption, the civil servant is the richest employee category in Cameroon (ZE, 2007; AYISSI, 2008). The presence of this category of people largely explains the better prevention capacity of these PA.

Figure 92: Illustration of a rural housing architecture within a densely populated area of Yaoundé (July 2007)

4.3.7.3 Socio-malarial identification of less exposed areas

Intermediate II and very dense categories of PA presented the lowest MRR. They are also the least crowded and the richest PA. All other things being equal, they also have the highest prevention coefficient. The intermediate II PA category represents criterion of high-standing zones; intermediate II PA are less dense than those of the very dense category, but not so isolated as those of intermediate I category. This suggests that they do not belong to a rural pattern, but correspond to planned areas where the presence of asphalt roads and of more space around individual houses distinguish them from both too rural and too urban patterns. They have the highest ratio of public servants. This information is important for a city like Yaoundé in which the vocation is to be in an administrative node (centralization of national administrative activities). Public servants used to be the predominant category in the city and had priority in accessing the present planned areas (MINISTÈRE DE L'URBANISME ET DE L'HABITAT, 1982; PETTANG, 1998).

The very dense PA are clearly the richest of all. They have the highest ratio of people involved in liberal activities. What also distinguishes them is the total absence of people involved in agricultural activities. What distinguishes them from the intermediate II PA category is the fact that their location partly corresponds to those of the MAETUR (Mission d'Aménagement et d'Équipement des Terrains Urbains et Ruraux) and mostly to SIC (Société Immobilière du Cameroun) zones. These are constructed zones, planned and developed by the government (Ministère de l'Urbanisme et de l'Habitat, 1982; Ministère de l'Urbanisme et de l'Habitat, 1996; PROUZET, 1996; PETTANG, 1998). The constructions of the SIC are extended zones with similar architecture. The acquisition or location of a parcel or a house was made by richest people. The uniformity of the architecture which is a modern one (compared to rural canons) explains the lowest crowding coefficient of these PA.

4.3.7.4 Better understanding of the spatio-temporal ecological impact on urban malaria

The difference between the seasonal highest and lowest malaria ratios of the extremely dense PA suggests that malaria is exclusively associated with agricultural activities within these PA, rather than with a natural extra-agricultural transmission pattern. In fact, this ratio is very low during the small rainy season (see tab. 27). Malaria is more prevalent during this season in the entire city. Extremely dense PA have one of the highest ratioS of malaria cases during the big rainy season. The hypothesis is that the big rainy season provides enough water to fill the adjacent water drains that are used for agricultural activities within these PA during these seasons.

The contribution of agricultural activities to malaria transmission during the big rainy season is also detectable through the comparison of seasonal ratios of malaria presence in extremely isolated, isolated and intermediate I PA. The suggestion is that transmission during the big rainy season is highly sustained by agricultural activities, while the transmission during the small rainy season is sustained by both agricultural and other natural processes (see tab. 27). Following this conclusion, the PA that are marked by a high presence of rural patterns show higher malaria prevalence during the small rainy season. This hypothesis is also sustained by the quasi-absence of malaria-transmission in very dense PA during the big rainy season. This assumption is based on the fact that very dense PA are the most distant to agricultural activities.

4.3.8 An important knowledge-base for Decision Making

Since the Fuzzy Logic expert knowledge-base was largely constructed from the IU, it could have been suspected that the results would follow the logic of the IU by showing a linear positive evolution of the membership from the most isolated to the densest PA. This is not the case; the results of the Fuzzification also identified the intermediate I PA category as being the most malaria prevalent one. Prediction values of malaria-presence ratios using the Fuzzy–based method were in general lower than the observed ratios, except for the intermediate II PA (see fig. 93).

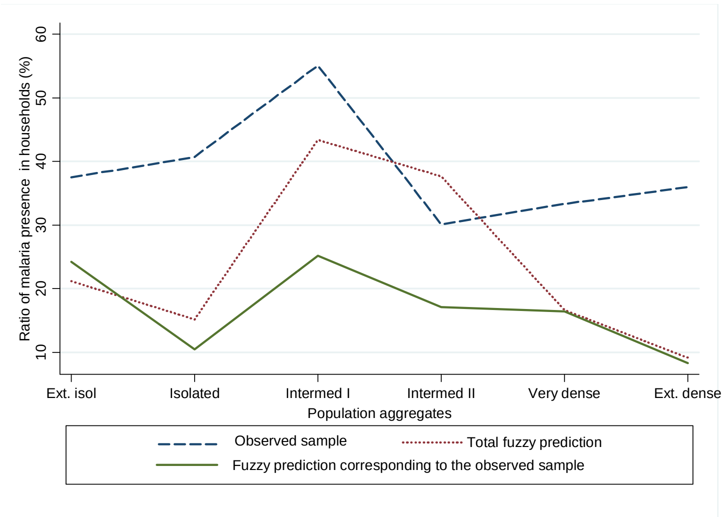


Figure 93: Comparison of Fuzzy Logic-based malaria presence prediction with observed malaria presence

The predicted malaria-presence-ratio is lower in the extremely dense PA than the observed one. The predicted malaria-presence-ratio of extremely isolated PA is lower than the observed one. These two categories, particularly the extremely isolated PA, also present the less correctly predicted malaria presence (see fig. 94).

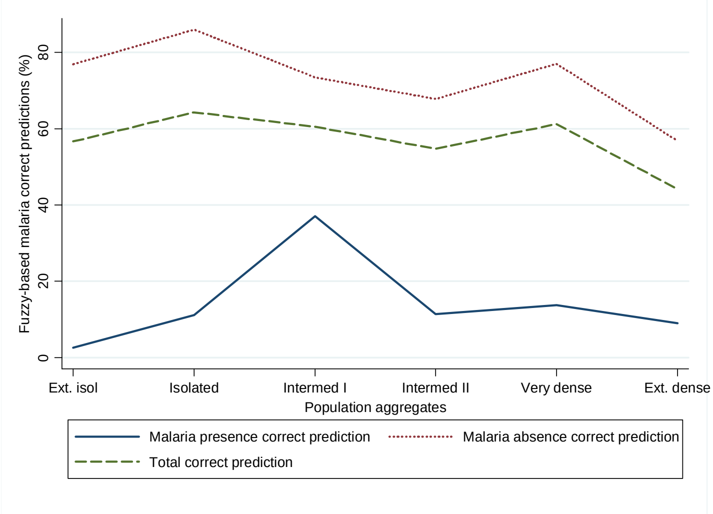


Figure 94: Evaluation of Fuzzy Logic-based malaria correct predictions

The results of the Fuzzy Logic-based prediction presented a total malaria presence correct rate (when only considering points extracted from the field surveys) of 13.21%, a total malaria absence correct rate of 69%, and an overall malaria correct prediction of 54%. With an overall household malaria prevalence rate (based on the counting of households not on the number of residents) of 15 %, the Fuzzy-Logic model presented a lower prevalence than the observed (27%). However, the analysis of the spatial distribution of the Fuzzy-based results at a higher spatial resolution than the PA showed similarities with observed malaria (see fig. 95). The mean values of observed malaria and those of predicted malaria at a district level are significantly correlated (CI=99%, R= 0.28).

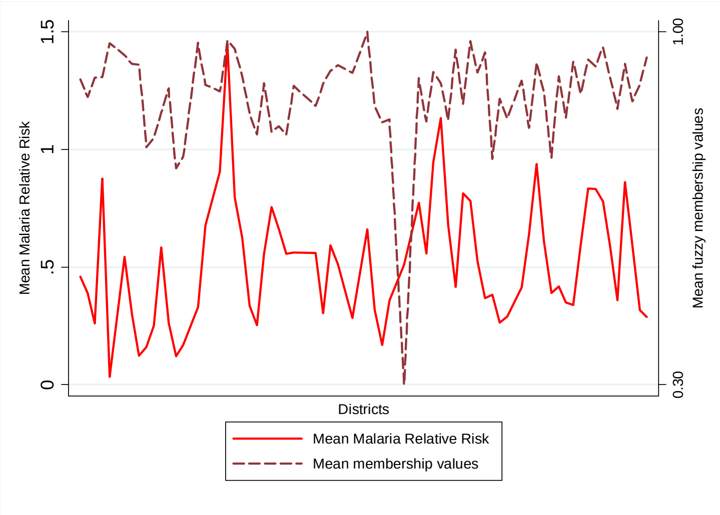


Figure 95: Fuzzy Logic-based malaria prediction vs. observed Malaria Relative Risk (MRR) at a district level

5 Pedagogical antimalarial tools and dissemination of malarial scientific information

Malaria prediction using a Fuzzy Logic method is the last step of a procedure aiming to simplify the urban malaria paradigm. The logic of this paradigm was interpreted into a statistical model aiming at the identification of key independent variables susceptible to be associated with urban malaria in Yaoundé. These key variables are the basis of the knowledge base introduced within the malaria-Fuzzy-logic predictive model (see fig. 96). Moreover the identified variables constitute the thematical fields on which malaria prevention strategies should be based. In fact and in a preventive perspective, it can be said that the actual models are at the service of prevention strategies. The malaria prevention concept that is treated in this chapter integrates the actual modelling results (see fig. 96).

The chapter emphasizes on an approach aiming to transmit comprehensive information. A large part of this chapter is dedicated to the explanation of the choice of tools hosting the produced malarial scientific information. A detailed explanation of the philosophy behind each choice is provided. Descriptions of technical aspects of the proposed pedagogical tools are also provided in this chapter. The chapter begins with an assessment of the population knowledge on malaria and ends with the measurement of the malarial-information transmission capacity of the proposed tools.

5.1 Locally adapted tools and comprehensive malarial information

The association of the level of malaria-knowledge of the population with socio-economic variables, on one hand, and that between the level of malaria-knowledge and the prevention behaviour on the other, were assessed through bivariate analyses. The idea was to see if the degree of malaria-knowledge is drawing a particular socio-economic profile. The intrinsic assumption is that all these variables are interrelated, the socio-economic status being an indicator of both the level of crowding and the prevention capacity. The level of malaria-knowledge was thus supposed to be an indirect indicator of the social vulnerability to malaria.

As stated in Chapter 1, all the antimalarial strategies seem not to help in reducing malaria prevalence. This empirical assumption clearly does not stress the complexity of the factors intervening in malaria-transmission. However, without pretending to create a panacea that will resolve the malaria-transmission risk problem, it seems like there is no adequate connection between the potential of available resources and their effective utilization for antimalarial campaigns.

Actors involved in the domain of malaria prevention in Cameroon, in general, and particularly in Yaoundé, are the Government through the Ministry of Public Health and various Non-Governmental Organizations (NGOs). The antimalarial campaigns are usually made through mass medias such as local television and radio. An important part of antimalarial communication campaigns is made through posters in hospitals. Some associations are using pedagogical means, such as theatre, to raise public awareness of malaria's problem. In order to briefly evaluate these empirical assumptions, interviews were conducted in five different schools of Yaoundé. Three hundred students were interviewed; they were asked about their awareness of malaria through the mass media (questionnaire in the appendix A).

In building the antimalarial pedagogical tools, one of the most important questions to solve was to choose the type and quality of the information to transmit. The idea was to avoid limiting the prevention capacity on bits of information only focusing on utilization of bed nets, but rather to have a more comprehensive approach integrating filtered information from

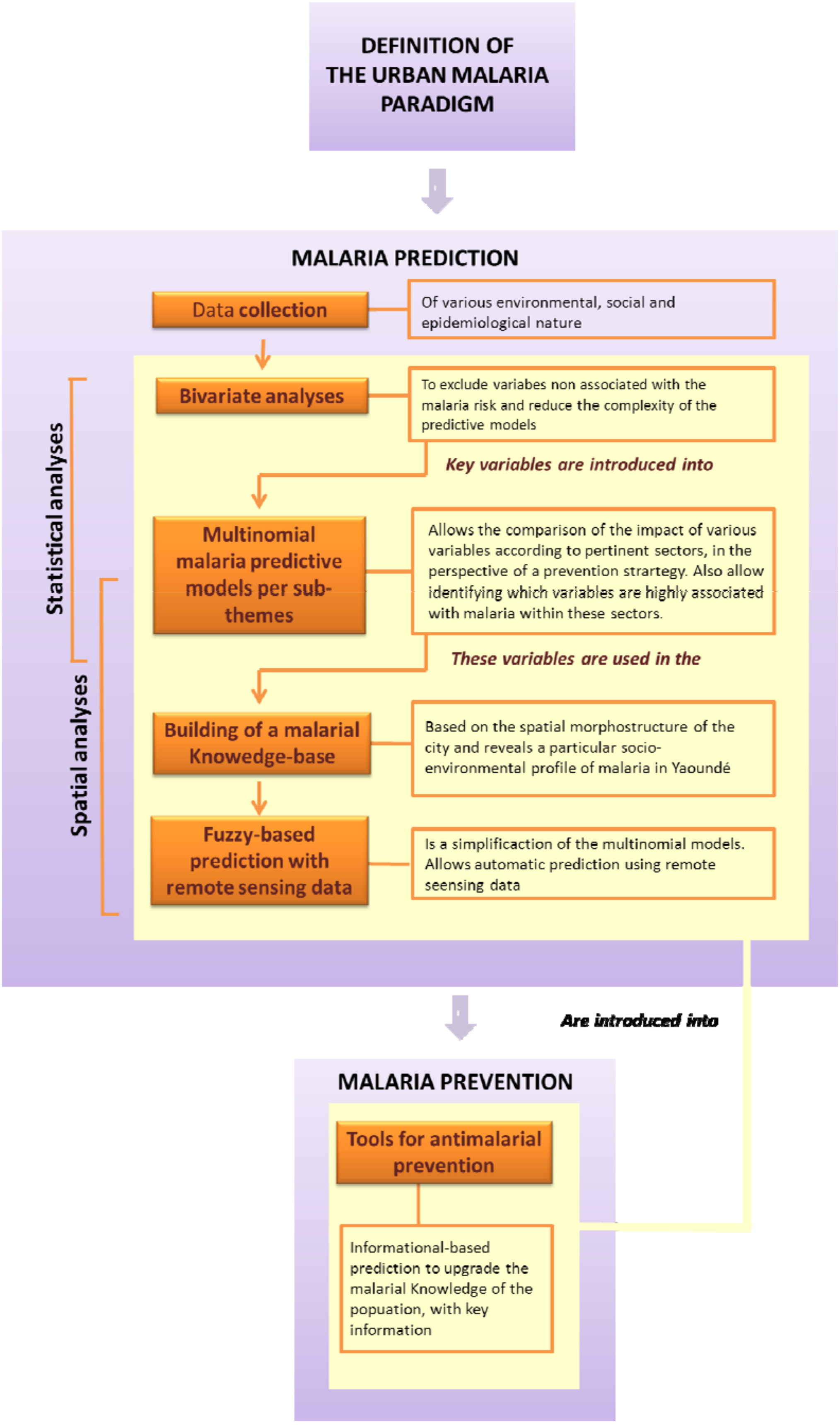


Figure 96: From malaria prediction to malaria prevention of global design of the concept

the elaborated models. The hypothesis is that a reasonable and sustainable reduction of malaria outbreaks needs an extended knowledge of elements intervening in its transmission. The utilization of the actual models as an information source helps in reducing the number and complexity of this information by only integrating the essential one. The transmitted information should integrate biological, economic, ecologic, as well as social and behavioural key aspects.

Another question concerned the targeted public to whom this information transmission should be addressed. The idea was to target the population according to both the demographical profile of the city and the physical accessibility to people. As related by all the demographical profiles, the population of the city is very young. Practically all of these youth (94% according to the National Institute of Statistics) is provided with schooling (INSTITUT NATIONAL DE LA STATISTIQUE, 2002). It looks reasonable to consider this category of the population without completely neglecting the other categories. In addition, it is easier to access this category of population through schools. Many schools are equipped with computers which is theoretically an attractive tool for children (see fig. 97).

Figure 97: Computer room in a high school in Yaoundé (August 2008)

Furthermore, the local educational system does not really propose a warning approach on what concerns the education/information-based processes of the population on malaria. This role is devoted to the Ministry of Public Health. Malaria, like other public health concerns, has never been taught and/or implemented as problems that could be integrated in the regular educational system. The range of educational tools usable for the education/informational processes of the population through the educational system includes other instruments than the computer. Other formal means can be used (courses, activities, libraries). However, school children must not be the only targeted audience. The dissemination strategy should integrate households and cultural centers.

Another essential question is to know into which format the information on malaria should be transmitted. The answer to this question should consider the previously developed hypothesis on the integration of demographical profiles as an indicator, and the utilization of resources of the educational system. Local cultural realities should also be considered. The high rate of unemployment in Cameroon, in general, and particularly inYaoundé, lead to expenses of energy into various games (see fig. 98). Betting on horses is, for example, one of the five best industries in the country. Playing games or simply drinking in bars is also frequent among Cameroonians (breweries are one of the five best industries in the country). Yaoundé is perhaps the only city in Africa where an entire street only composed of bars can be found (The street of “montée Mvog-Ada” is the most famous one). Even students used to leave the classes in order to play video-games in bars. Bars are places where political and social as well as psychological frustrations are dissolved; they are places where networks of social exchanges are established beyond social and cultural differences.

Figure 98: Children playing original local games (A) and (B) and young adults playing scrabble in the streets of Yaoundé (C) and (D) (June 2007).

From this empirical observation it looks obvious that games of various formats are much appreciated and used by the citizens. From this remark, it can be hypothesized that games constitute excellent support for the transmission of information on malaria, in general, and malaria in Yaoundé particularly. This hypothesis can also be supported by the fact that games are softer and digest in the information-transmission process than most of the other classical pedagogical tools (BLOOM, 1969; ANDERSON & KRATHWOHL, 2001; HAYDÉE SYLVA, 2009).

5.2 Various types of games for objective criterion

Once the choice to translate the filtered information on games was made, the question of the format had to be resolved. The formats were chosen according to various criterions. The first criterion is based on the distributional possibilities of the games. The physical, ergonomic aspects of the games have to be adapted for an ease and widespread distribution in various strategic places. The second criterion is the pertinence of the games. They have to be interesting enough to attract potential players. The last criterion is that of the adaptability of the information to various supports (computerized and non-computerized).

In order to respect these criterions, three types of games with various physical formats and various information-carriage capacities were created. The first one is a social non-computerized game called Malariaquiz. Its informative aspect was supposed to be more important than the fun aspects. The second game is also a social non-computerized game called Malariapoly; its informative aspect was supposed to be less important than its fun aspects. The last game is called Geomalariaquiz. This is a computer-based game, which was supposed to have a good mixture of the fun and informative aspects (see fig. 99).

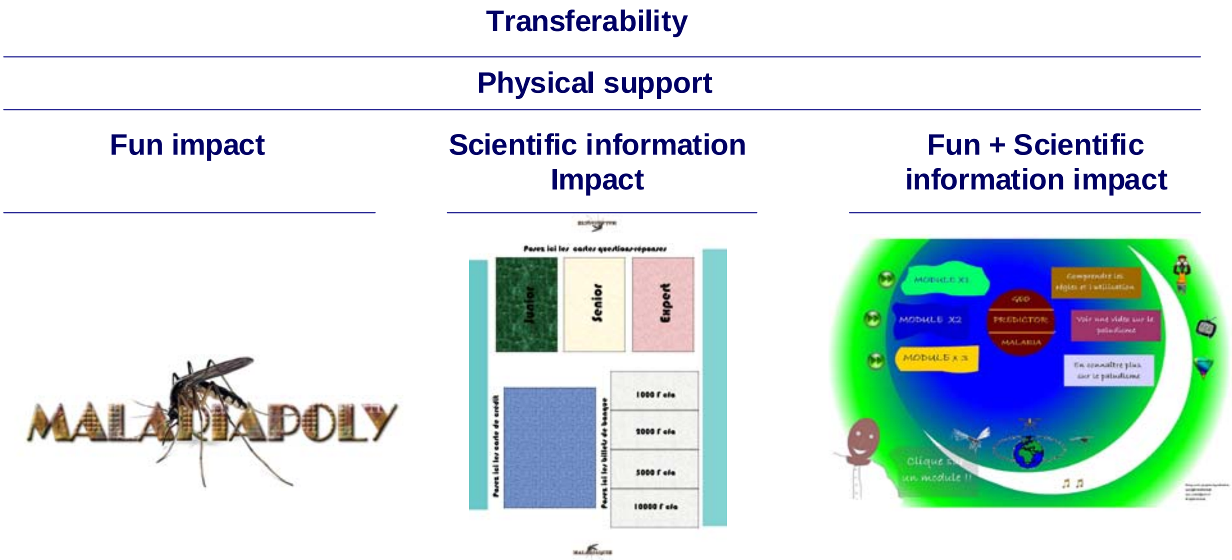
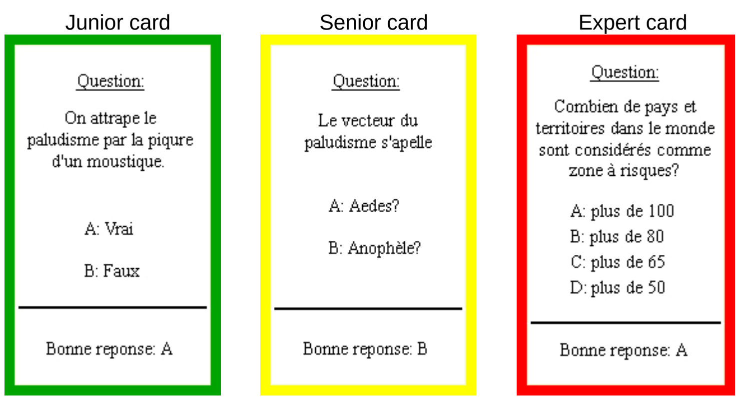


Figure 99: Three kinds of games with different kinds of physical and informational supports

The Malariaquiz is a quiz with three separated levels of questions. The first level, called the junior level, has forty questions (see appendix B); they were concerned with general basic information on malaria and its biological, as well as ecological, associated factors. The senior and the expert levels have each twenty questions; they are much more concerned with epidemiological and clinical issues of malaria (see fig.100). The game also had a support frame as well as virtual local money the Franc CFA and a two page document to explain the rules of the game (see appendix B).



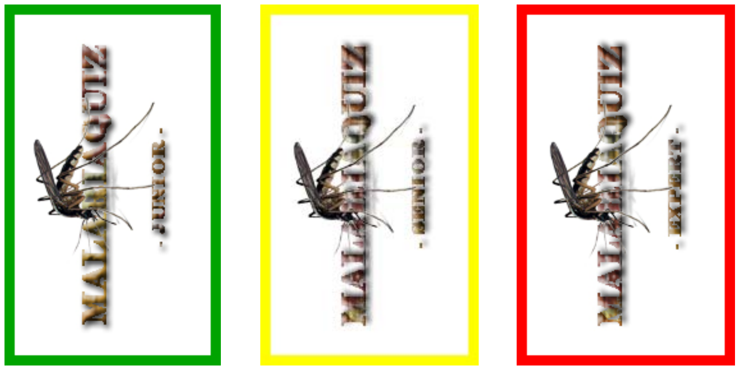


Figure 100: Prototypes of the two sides of the Malariaquiz

The presence of virtual local money is an added value in comparison to the other quizzes. The objective is to create a motivation to play by earning the money. At the end, the richest of the players is the one who performed well in answering questions. The value of an earning depends on the level of difficulty of the question. Expert questions are the most valuable while the junior questions have the lowest value. Detailed documents are available in the appendix. The cognitive process of information transfer is visual (reading the questions and answers) and oral (listening to the questions and answers).

The Malariapoly was made on the image of the Monopoly, the ever most successful of all the games (GUINESS WORLD RECORDS, 2007). The rules were globally the same as in the Monopoly, with the exception that lands are substituted by the districts of Yaoundé. The value of a land is proportional to its malaria risk. The higher the risk, the lower the land value. A figure such as prison is replaced by a hospital, treasures were replaced by clinics, polyclinics, medical laboratories analyses and drugstores. A virtual map of malaria risk for each district is placed in the middle of the game (see fig. 101).

Figure 101: The Malariapoly and its elements

Penalties are given according to the bad actions that are favouring the risk: unclean environment, buying drugs on the street, no bed nets. Rewards are also given for the reverse unfavourable transmission risk conditions. These penalties and rewards are mostly present within “chance” and “community” cards. Virtual figurines replacing houses and representing hospitals and clinics were made in wood by a local craftsman. Virtual local money is also made and used in addition to the specific money that is common with the Monopoly (see fig. 101). A four page document explaining the rules of the games is added (see appendix).

The cognitive process of information transfer is visual: reading the items, visualizing the iconography and suggestive objects. It is also sensorial: touching the figurines with various dimensions was giving the feeling of difference. Hospitals are given a bigger dimension than simple clinics. The cognitive information transfer process is also oral: listening to the penalties and rewards, buying and exchanging lands among players.

The Geomalariaquiz is a web-oriented computer based game. It is programmed with flash under Flash MX of Macromedia Inc. The game mainly consisted of two modules: one mainly representing the ecological aspect of the fundamental scientific results (module X1), and the other one much more representing the social aspect of the scientific results (module X2) (see fig. 102). A page explaining the rules of the games was also provided at the introduction (see fig. 103). The opportunity to watch a video on malaria as well as to read more about malaria with online chosen links is also possible.

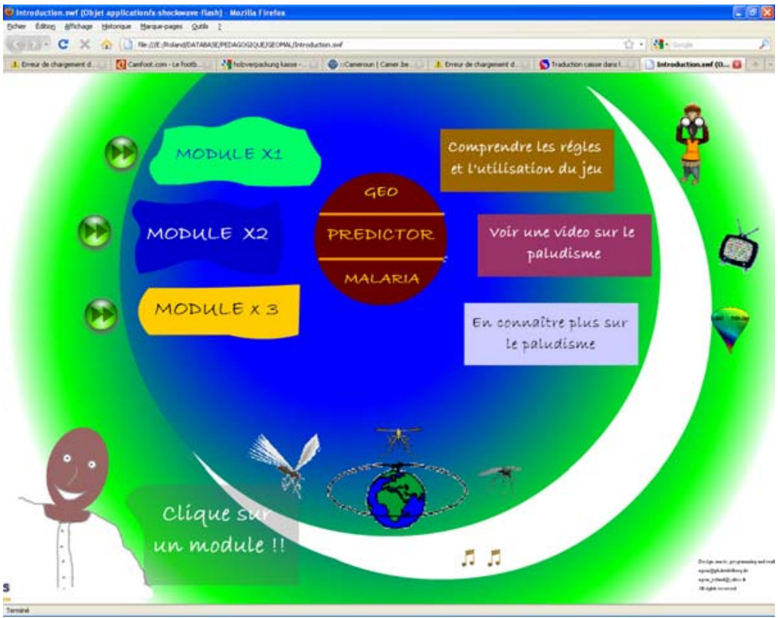


Figure 102: Introductory page of the Geomalariaquiz

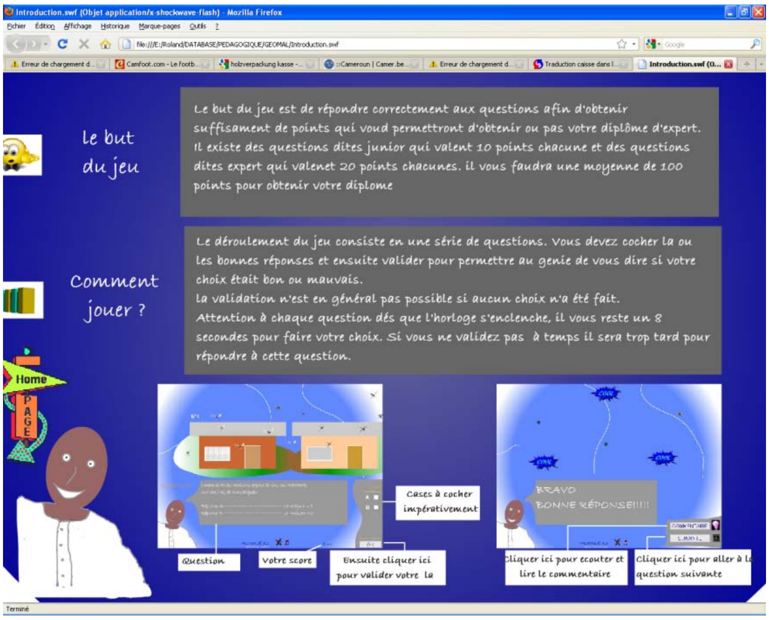


Figure 103: Page explaining the rules of the Geomalariaquiz

A character playing the role of the interlocutor was created. His role is to ask the questions and give the verdict as well as to give the good answer (see fig. 102 to 106). In fact, for each question a detailed answer is furnished (see fig. 105). The questions and answers are given in a graphical and audio way. Audio scenarios were professionally recorded. In addition to the questions and answers, sequential music (original composed themes) and special effects are added.

Figure 104: Example of page after a good answer in the Geomalariaquiz

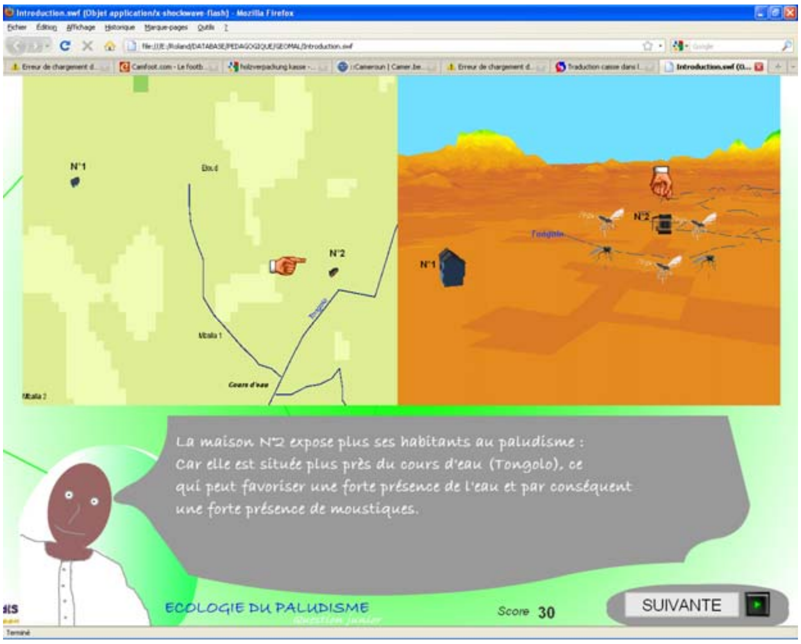


Figure 105: Example of an answer to a question provided by the Geomalariaquiz:

The questions use a multiple-choice design; each module has junior and expert questions. Junior questions are very basic and are iconographically very suggestive. Each module has a total of 12 questions (see appendix B). Each question is timed with a stopwatch, and the game is based on a score. Expert questions have a higher point value than the junior questions. At the end, each player can obtain his score (see fig. 106) and earn a diploma (see fig. 107 and fig. 108). The diploma makes it possible to collecte detailed information on date, name, the game session, age, gender, level of study, and place as well as details of the performance on each question/item. All this information was usefully introduced into further analyses.

Figure 106: The Geomalariaquiz is score-based

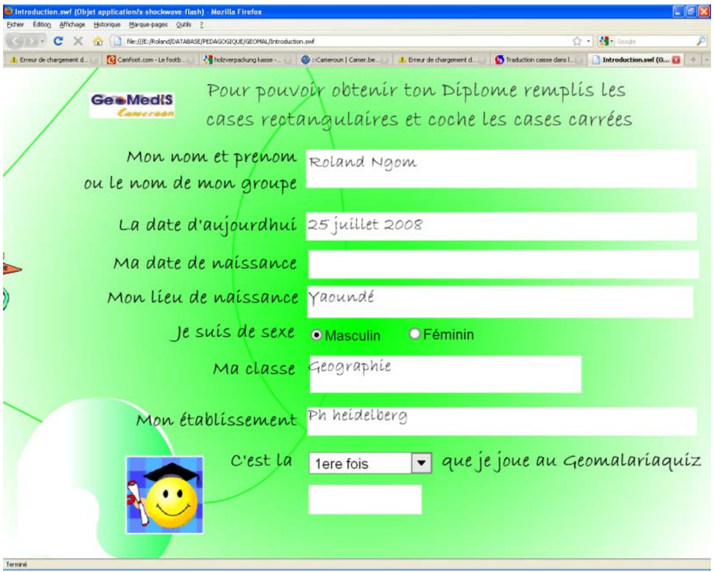


Figure 107: Own diploma self-elaboration procedure in the Geomalariaquiz

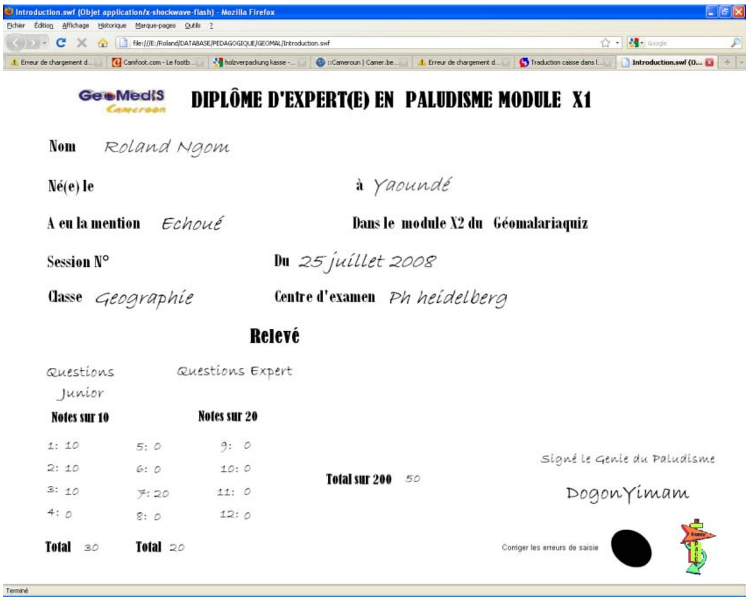


Figure 108: Geomalariaquiz, possibility to retrieve strategic information for further analyses

5.3 Assessment of the information transmission capacity of the games

For each of the games players/subjects were randomly chosen. Games sessions were mainly conducted in households. The Geomalariaquiz was performed both in households and schools. The Malariaquiz was performed both in households and cultural centers. All the games sessions were organized and conducted with the assistance of the supervisor. Before playing, the surpervisor had to explain the rules of the games. In most of the sessions, the supervisor was also a player with the exception of the Malariaquiz games sessions.

The surveys are composed of 32, 28 and 64 players/subjects for respectively the Malariaquiz, the Malariapoly and the Geomalariaquiz. There were more males than females within these surveys (see tab. 30). The minimum age of the players was 11 and the maximum 36. This wide range of ages allowed assessing the adaptability of the games to notably the youngest players. Although the players are mainly school children from primary and high level (80%), there is an important part of players having various socio-economic status: employed, jobless, students.

Games	Males	Females	Age range	Median age	Mean age
Malariapoly	55%	45%	11 to 36	30	28
Malariaquiz	80%	20%	11 to 32	14	14
Geomalariaquiz	61%	39%	7 to 36	16	17
Total	67%	33%	7 to 36	17	18

Table 30: Demographical summary statistics of the players of various malaria games

A pre-and post-test-method was applied to each game in order to assess their information transmission capacity. The method consisted of a questionnaire completion before and after the play (see fig. 109).

The same questionnaire was used before and after the play. Crossing-over questions/items were provided in the games. It means that each question in the questionnaires had a corresponding item/question in the games. The questionnaires used to evaluate the impact of the Malariaquiz and the Malariapoly were identical, while the questionnaire used for the Geomalariaquiz was unique (see appendix). The objective was to evaluate the progress made by the players after the play session(s).

A crossing-over matrix was used in order to allow statistical evaluation of the progress made by the players/subjects. The matrix took the form of two tables. The first one provided a clear and precise correspondence between questions in the questionnaires and questions/items in the games. Because it was not possible to monitor the action of each player during the game sessions, utilization of this table was not optimal in the case of the Malariapoly and the Malariaquiz. Said in other words, it was not possible to monitor each sequence of answers players gave while they were playing. Because the Malariaquiz was programmed to monitor the action of each player, a detailed evaluation was possible.

This table was used as a reference for the distribution of scores made by the players on the basis of the matching of good answers in the questionnaires. In the case of a corresponding good answer, the player was given a score of 1/1 for this question. This rule was applied both for the pre- and post-test questionnaires (see fig. 110). It was then possible to build a table showing the scores (before and after each play session) of each player.

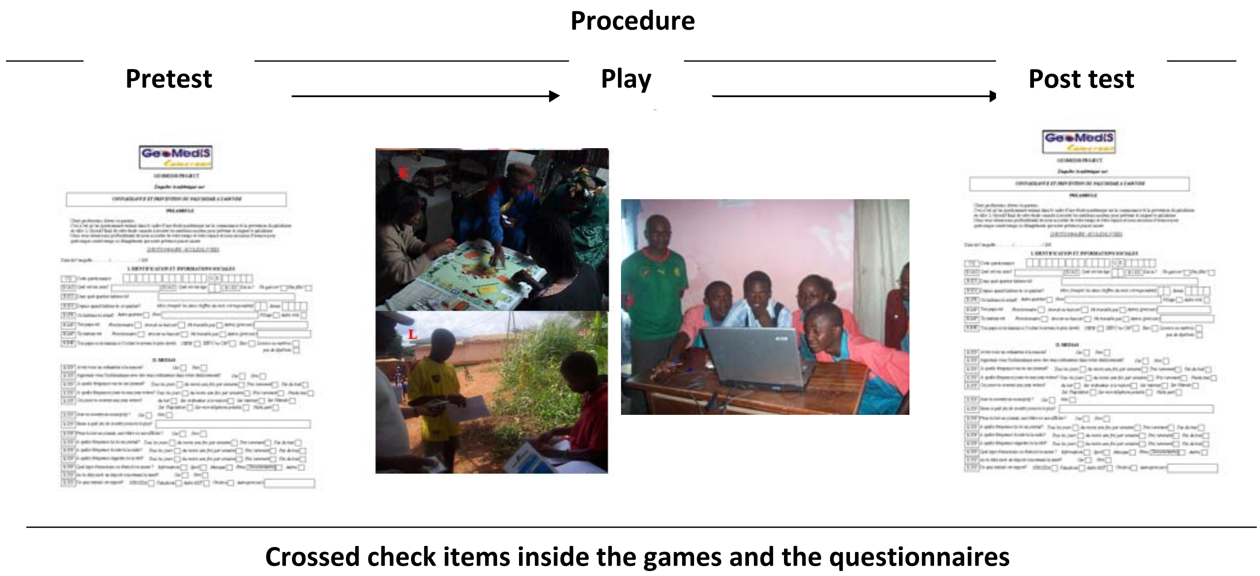


Figure 109: Concept of the pre- and post-test assessment method

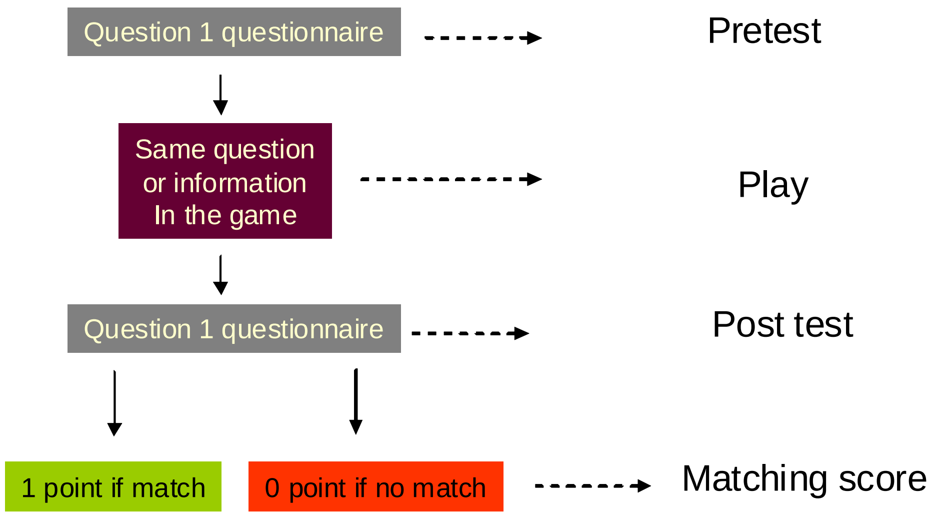


Figure 110: Scoring process of matching between questionnaires and games

The potential impact of the games was measured through the matching scores. The matching score S_{PM} of each player corresponds to a total number of good matching answers G_{PMGA} over the total number of matching questions Q_{TM} in the questionnaires:

$$S_{PM} = \frac{G_{PMGA}}{Q_{TM}} \tag{44}$$

It is useful to recall that matching items were corresponding to an identity between the questionnaires and the game contents. The matching scores were calculated before the play $S_{PM,t0}$ and after the play $S_{PM,t1}$. It is possible to evaluate the progress in matching scores Pgr_M by finding the difference between the two scores:

$$Pgr_M = S_{PM,t1} - S_{PM,t0} \tag{45}$$

For players who performed several times only the last session $S_{PM,\,tn}$ was considered:

$$Pgr_M = S_{PM,tn} - S_{PM,t0} \tag{46}$$

An additional player's performance indicator was calculated. It corresponded to the scores $S_{PQ,\,tn}$ of the players after play. This indicator does not consider the matching aspect of the questionnaires but only the good answers G_{PGAQ} in the questionnaires:

$$S_{PQ,\,tn} = \frac{G_{PGAQ,\,n}}{Q_T} \tag{47}$$

Since many questions not directly or explicitly corresponding to an item in the games were included in the questionnaires, $S_{PQ,}$ helped in the quantitative assessment of the potential impact of the games on the general level of knowledge of the players. Since the matching questions were assumed to be thematically closed to no matching questions, the hypothesis is that a good matching score is an indicator of progress in general malaria information acquisition. However, this general level of knowledge could also be attributed to a chance factor. For this reason, it is also important to consider general performances in the questionnaire, excluding the matching factor. This general performance is evaluated by finding the difference between the score $S_{PQ,\,t0}$ in the questionnaire before the play with that after the play $S_{PQ,\,tn}$:

$$Pgr_Q = S_{PQ,\,t0} - S_{PQ,\,tn} \tag{48}$$

Bivariate analysis aiming to evaluate the association of the progress in matching scores Prg_M with several factors were performed using the Fisher's Exact Test. The selected independent variables were: age, gender, level of study, usage of the same kind of games, progress in questionnaires Pgr_Q matching score $S_{PM,tn}$.

A qualitative appreciation of the games was made by the players. This appreciation was concerned with the rules of the games, their format, their attractiveness and their educative impact (see fig. 111). The main objectives were to evaluate the games'attractiveness and physical reliability.

An additional qualitative appreciation was made by a small sample of teachers. They were asked to give a free pedagogical appreciation on the games. This appreciation was made after a play and was only applied to the Geomalariaquiz. An overall appreciation of all the games based on all the described statistical indicators was performed in order to estimate the impact of all the games together.

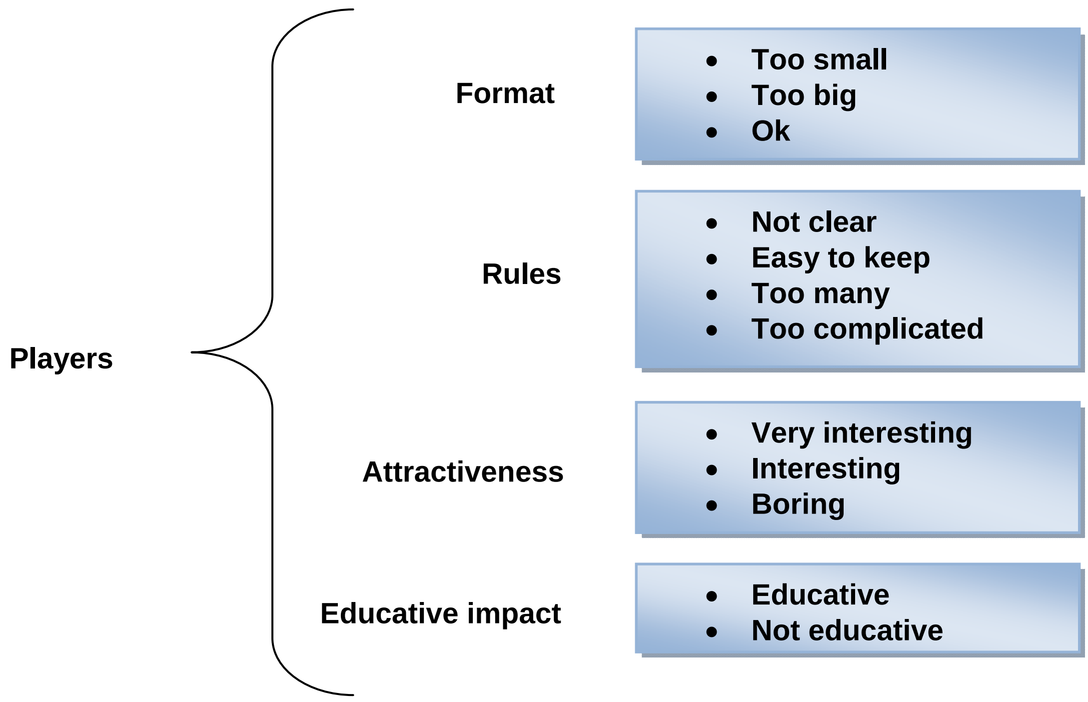


Figure 111: Qualitative factors of games' appreciation by the players

5.4 Positive qualitative feedback and effective information transmission capacity

5.4.1 Socially stratified level of malaria knowledge

A total of 99% of the interviewees from the household survey do not know that malaria vector is biting only during the night; 97% of them made no link with the role of the vegetation in malaria-transmission; 93% of them did not mention the presence of water as a potential malaria favouring factor; 14 % of those surveyed had no idea of the elements intervening in malaria-transmission; 79% of the population cited mosquitoes as an element intervening in the transmission of malaria.

No clear indications of the answers were given to the respondents. The objective of this question was also to empirically measure how far malaria is mentally associated with elements not intervening in the exposition. A recurrent answer relating malaria with mangoes frequently intervened. Many responders made a direct link between eating mangoes and having malaria. Empirical explanations could be found in the seasonality of mangoes production, which corresponds to that of highest malaria prevalence. Another explanation could be found within the symptoms of other seasonal affections, like amibiasis, which create confusion. These misinformations and confusions give an idea of how far a comprehensive communication not only on malaria, but on many other fatal illnesses, is lacking among the population.

However, none of these variables was significantly associated with MRR, which suggests that the level of malaria knowledge is not directly intervening in the burden or decline of malaria risks. But rather, it influences and can be influenced by other socio-economic factors of a more direct importance to malaria. The level of malaria knowledge is highly and significantly associated with the prevention coefficient (see fig. 112). All other factors being equal, the EC is also positively and significantly associated with the level of malaria knowledge (see fig. 113). It means that richest people are not only the better informed about malaria and the elements of its transmission, they are also the most protected against malaria. This conclusion is made on the basis of former analyses and is confirmed by the fact that people involved in informal activities have the lowest level of malaria-knowledge coefficient while people employed in liberal activities have a very high level of malaria-knowledge coefficient.

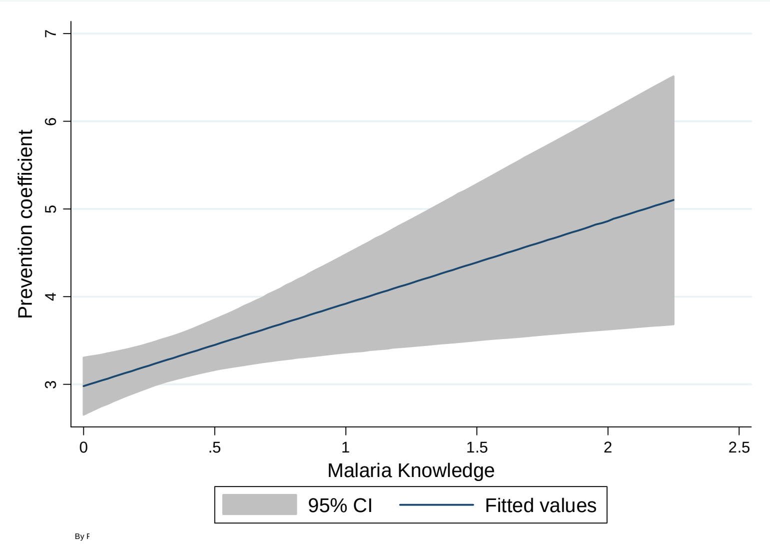


Figure 112: Level of malaria knowledge vs. Prevention coefficient

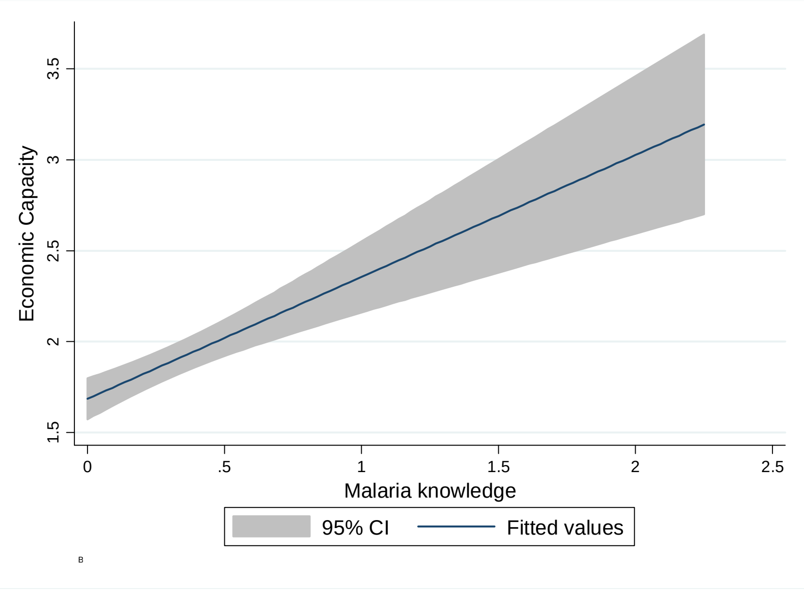


Figure 113: Fit between the level of malaria knowledge and Economic Capacity (EC)

5.4.2 IT communications-a misused potential of urban areas

The results of inquiries related to the usage of mass media among school children show that 59 % of them used the television, 15% used the radio, 10% used the press, 9% the posters, and 7% all the other channels possible, includingthe Internet (see fig. 114).

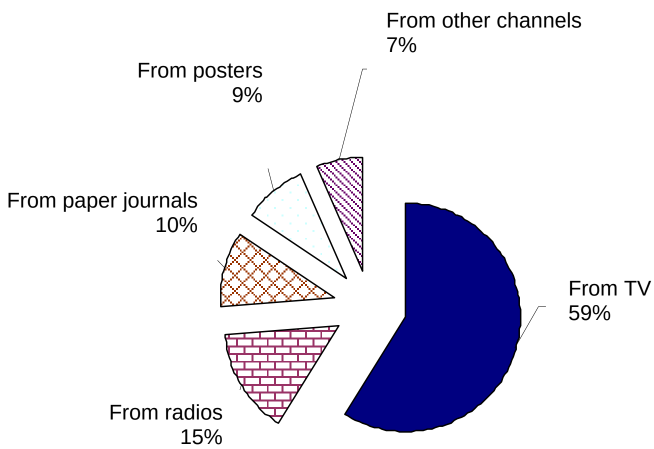


Figure 114: Malarial information through mass Media

Despite the fact that the survey (for reasons that will be given later) was composed of only students, it gives a good snapshot of the variability and the impact of tools used for antimalarial campaigns. In fact, the most frequently used mass medias have several limitations in transmitting a set of information that could lead to a global understanding of factors favouring malaria-transmission. In addition, the 7% corresponding to other medias are neglected.

Cell phones, computers and various tools that are related with cultural realities of the citizens are found in the 7% of communication channels that are neglected by the public authorities and NGO's. Cells phones are the most widely distributed communication tools in Cameroon, in general, and specifically in Yaoundé. In 2005, it was estimated that 2 million people owned a cell phone in Cameroon (KOUDJOU, 2006). Since this industry is actually the best one in most of the SSA countries, this number has certainly exponentially increased. In a country of about 14 million inhabitants, this has great potential for any campaign. However, like the televisions and radios, the effective utilization of such a tool is largely dependent on commercial decisions. Cell phones offer an excellent interface for the dissemination of more elaborated information on malaria. Computers are practically not limited by commercial decisions. Their utilization for antimalarial campaigns can be thought as internet, intranet or extranet tools. The computer is actually seen as an urban tool. Most of the citizens have access to computers through internet cafes. A large number of schools are equipped with computers that allow students to access the internet (see fig. 115).

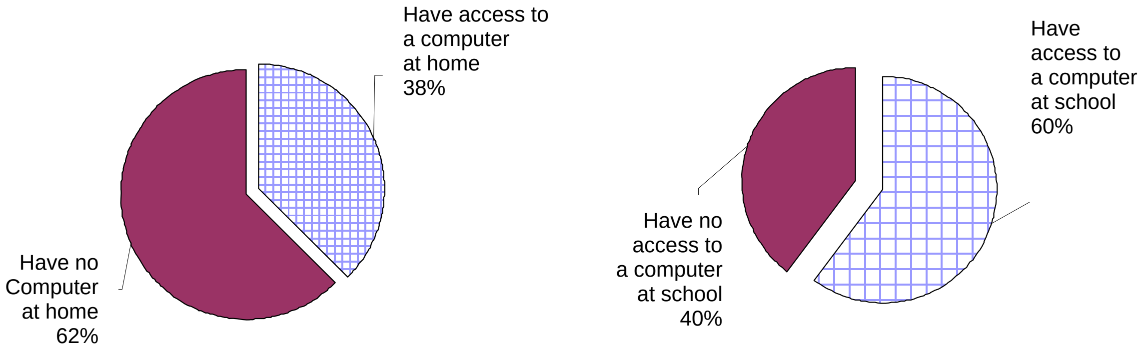


Figure 115: Access to computer at home or at school

5.4.3 A positive qualitative feedback from players

During the play-sessions, all the players showed a real and very encouraging interest in the antimalarial games. The Malariapoly and the GeoMalariaquiz were the most enthralling. One of the Malariapoly game sessions lasted longer than seven hours. Remarks dealt with self-appreciation of the players with their own words. They were so various that it was much better to sum them into positive and negative items. The GeoMalariaquiz is the game that was the most positively appreciated by the players; it summed 90% of the total positive remarks (see fig. 116).

However, the GeoMalariaquiz counted for 50% of appreciations indicating that the rules of the game are complicated. At the same time, 63 % of the appreciations indicating that the rules of the game are easy to keep were attributed to the GeoMalariaquiz. The Malariapoly was appreciated as being a game with too many rules, while the format of the Malariaquiz was found too small. On the question of whether the game was educative, meaning if they found the games informative, 92% of the players gave a positive answer (see fig. 117). Figure 118 illustrates chosen positive appreciations from various players and one appreciation of a high school teacher.

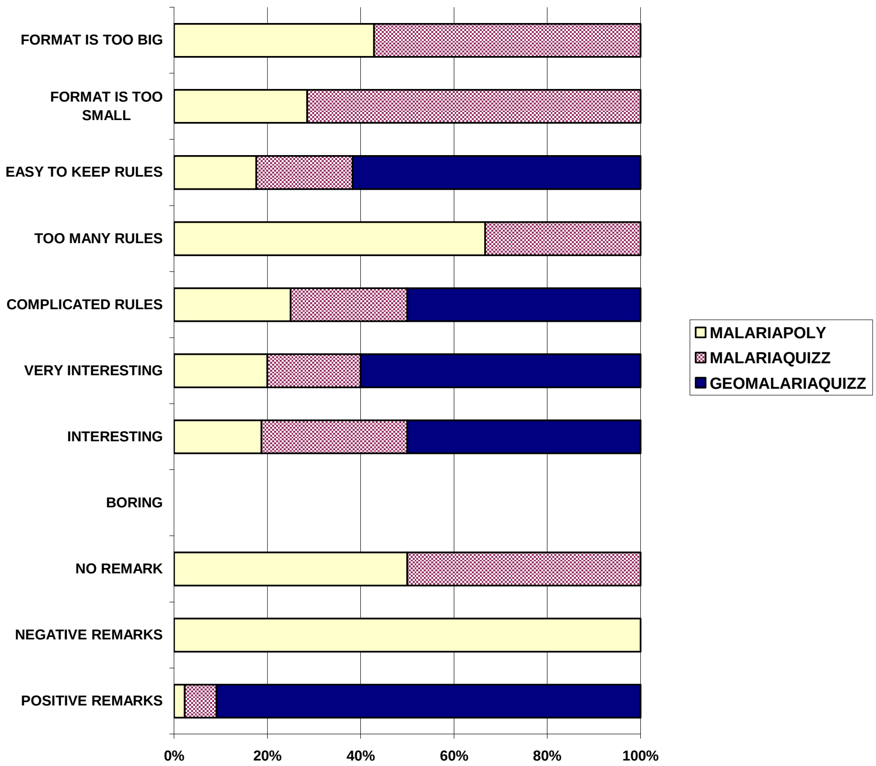


Figure 116: Compared-based appreciation of the three games by the players

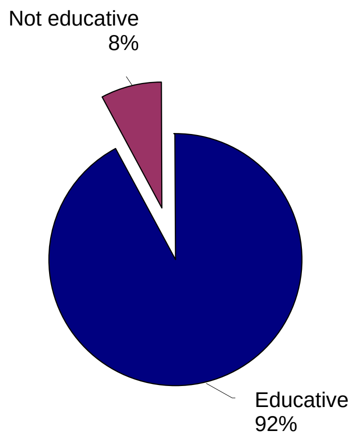


Figure 117: Answers of the players concerning the educative aspect of the game

PLAYERS

Malariapoly:
„Educative“
„Helps preventing malaria“
„We are paying too much“
„No time fixed for the end“

Malariauizz:
„Instructive“
„Educative“

Geomalariaquiz
„Helps preventing malaria“
„This game helps the player to upgrade his knowledge on malaria“
„This game helps for a better knowledge of prevention methods“

A TEACHER

Geomalariaquiz

«The Geomalariaquiz is a multidisciplinary game in relationship with our programs.
This is an effective pedagogical support adapted to the observation cycle (iconography) and to the specialization cycle (biology, geography, public spiritedness)
The evaluative aspect is relevant to it's adaptability at all level of teaching»

Figure 118: Answers of the players concerning the educative aspect of the game

5.4.4 Frequency of game sessions-a decisive factor

5.4.4.1 GeoMalariaquiz-a good information transmission capacity

With a progress percentage of 56%, the GeoMalariaquiz showed the best progress in matching questions score S_{PM} (see fig. 119). The Malariapoly has the worst progress rate, but a high rate of stable performances and no case regression in the players' performances. The Malariaquiz also showed a good rate of progression in the players' performances.

The high regression-rates of both the Malariaquiz and the GeoMalariaquiz suggest that those games are too informative or questions are complex or both at the same time (modules in those two games were organized according to the level of complexity of the questions). This complex aspect has no impact on the real information transmission capacity of the GeoMalariaquiz. The GeoMalariaquiz showed a positive and significant relationship with both the progress in questionnaires and the matching scores (see tab. 31). It means that good scores obtained by the GeoMalariaquiz players after the play, are really associated with the acquisition of information during the play. This is not the case with the Malariaquiz, which seems to be too informative or complex particularly for the youngest players.

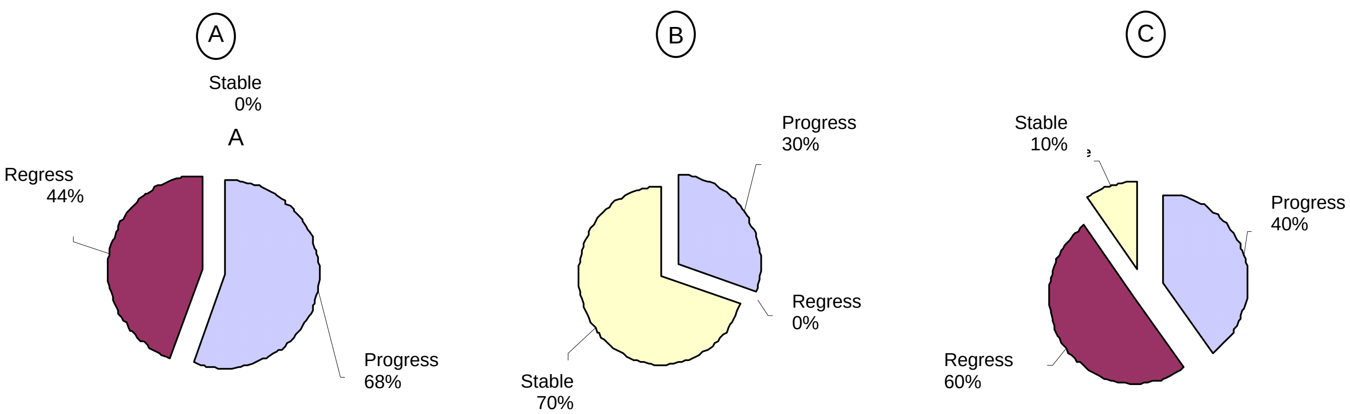


Figure 119: Total players performances based on matching scores of the GeoMalariaquiz (A), the Malariapoly (B) and the Malariaquiz (C)

The progress attributable to the Malariapoly is also real in the regard to the significant relationship with progress in questionnaires. But the non-significance of the matching score itself and the high rate of stable matching scores suggest that the majority of the players already had the good information (answer) before the play (Malariapoly had the fewest number of matching items). Gender, level of study and the usage of the same kind of game were not significant variables.

Malariapoly	**Malariaquiz**	**GeoMalariaquiz**
Age	**Age***	Age
Gender	Gender	Gender
Level of study	Level of study	Level of study
Used to play with the same kind of game	Used to play with the same kind of game	Used to play with the same kind of game
Progress in questionnaire*	Progress in questionnaire	**Progress in questionnaire**
Matching score	Matching score	**Matching score***

**Significant with Fisher's exact test at CI=95%*

Table 31: Bivariate analyses results using the progress in matching scores as dependant variable

5.4.4.2 Difficult questions

Junior questions of all modules of the GeoMalariaquiz are easier than the expert items. The module X2 of the GeoMalariaquiz that is dedicated to the socio-economy of malaria is the most accessible to the players. Overall performances of the players are better for this module than for the module X1 which was dedicated to the ecology of malaria (see tab. 32).

Variable	Mean	Median	Mode	Std. Dev.	Min	Max
Junior questions Module X1 (Ecological)	74.16	75	75	21.25	25	100
Expert questions Module X1 (Ecological)	37	37	25	18.41	12	75
Total questions Module X1(Ecological)	44.5	47	30	16.73	15	80
Junior questions Module X2 (Socio-economic)	96	100	100	12.03	50	100
Expert questions Module X2 (Socio-economic)	44.2	50	50	12,28	12	62.5
Total questions Module X2 (Socio-economic)	54.58	60	60	11.5	25	70

Table 32: General statistics of the GeoMalariaquiz player's performances

A large part of this weak performance of module X1 is attributable to the high number of spatial related questions associated with this module (see fig. 120), but also to the bad performances of the players on seasonal malaria items. Performances on junior questions were better than those on expert questions. Among the most difficult items of module X2 were those mixing prevention and EC (see fig.121). This result suggests that the success of the information transmission is dependent on the level of difficulty of the question/item. Almost all of the expert questions are asking for additional intellectual efforts from the players (see fig. 120).

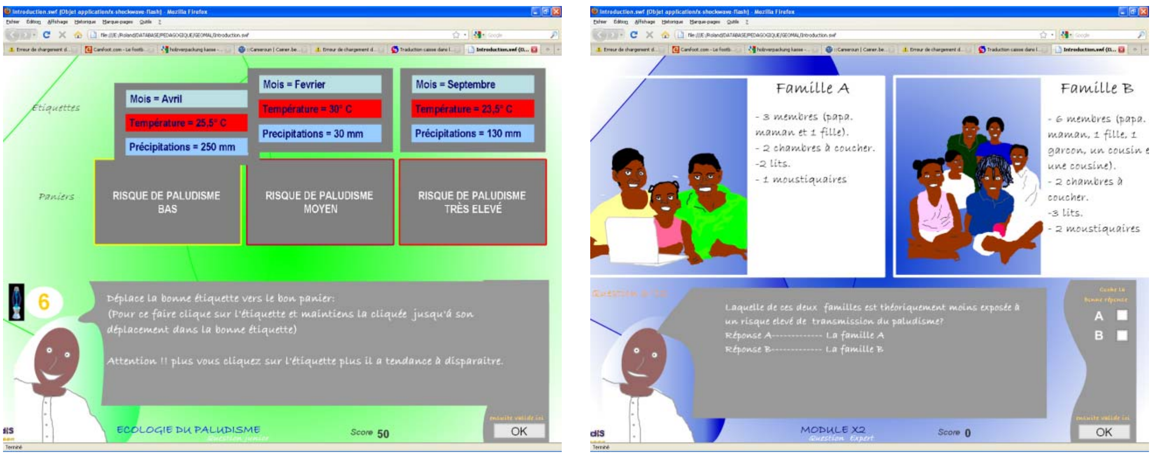


Figure 120: Examples of expert questions having multiple parameters and requiring a higher intellectual effort in the Geomalariaquiz

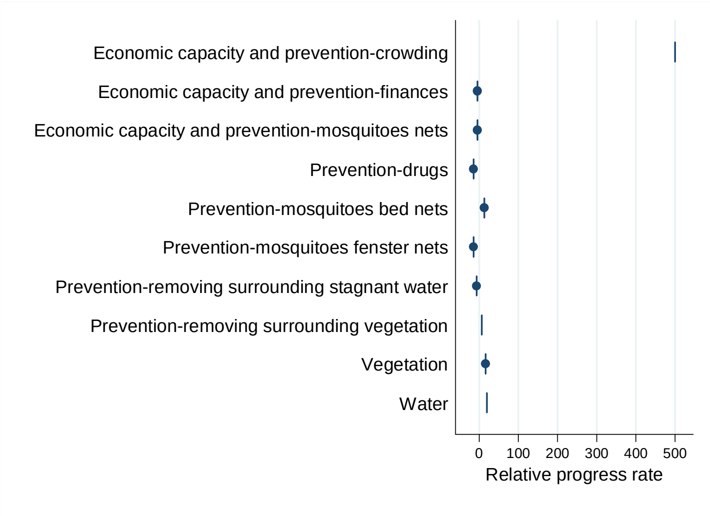


Figure 121: Relative progress of the players by socio-economic items

Questions having demographic or spatio-temporal content were also difficult to answer. Images requiring cognitive recognition of objects and questions related to resources optimisation through map analysis were very difficult to answer. Despite the fact that the right information was introduced as a reference in the GeoMalariaquiz for a better understanding (see fig. 122), players performed very badly on those items (see fig. 123).

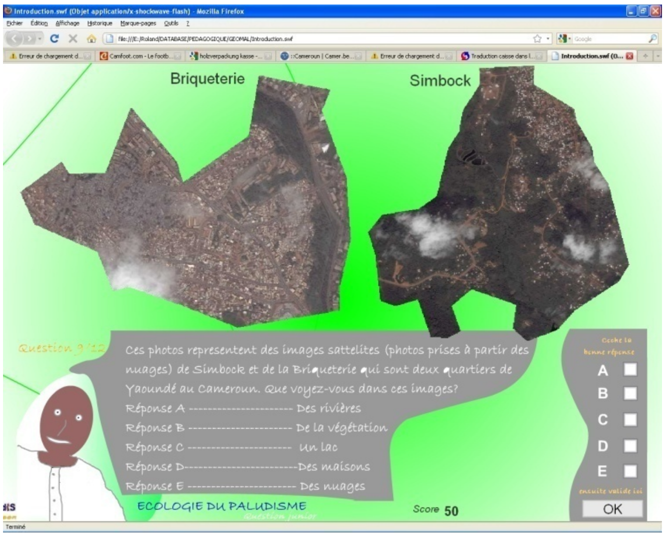


Figure 122: An example of spatial related questions requiring visual recognition

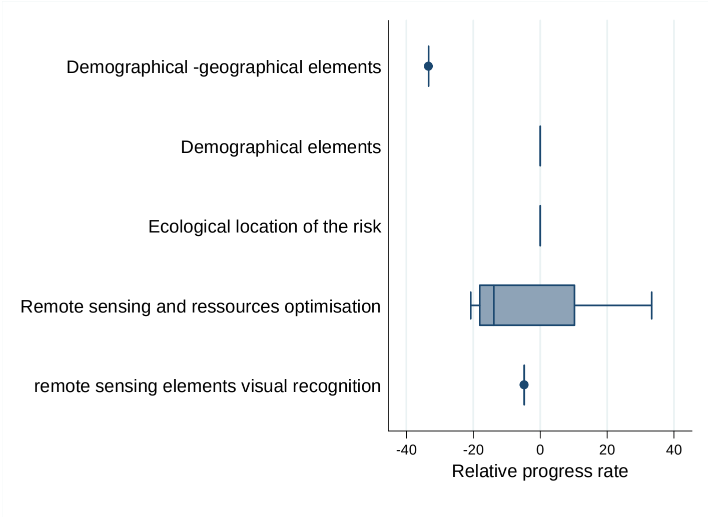


Figure 123: Relative progress of the players by demographical-spatial items

Among the easiest questions are those relating to the role of water, vegetation and climate elements in general (in the exclusion of the seasonal variability). The good performances can also be associated with the simplification of the iconography produced for the most well treated items (see fig. 124 and fig.125).

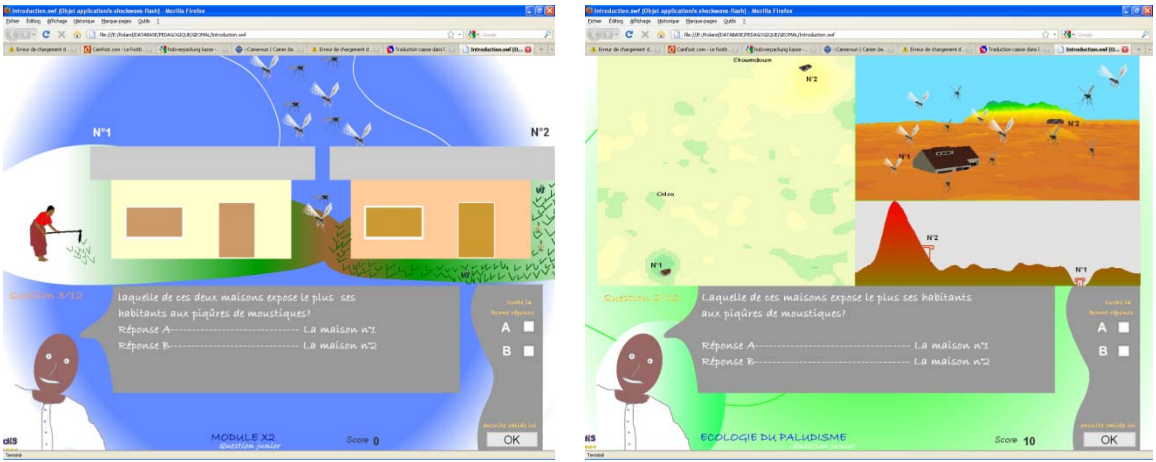


Figure 124: Examples of junior questions having a very suggestive iconography

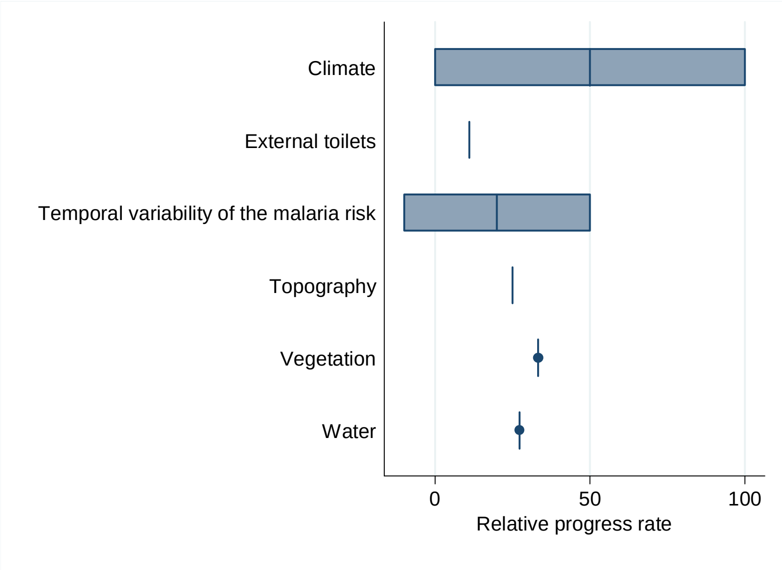


Figure 125: Relative progress of the players by ecological items

5.4.4.3 The number of play-sessions is significant

A closer examination of the relationship between the variable level of study and the scores of the players after the last play shows that the players with no diploma did better than the others (even if this relationship is not significant) (see fig. 126). Another observation focusing on the relationship between the variable age and the most difficult part of all the modules of GeoMalariaquiz (Expert module of X1), suggests that difficulties in answering questions could not be attributed to the age factor. This last correlation is significant with a Fisher Exact Test (see fig. 127). These figures are explained by the last one (see fig. 128), where it can be seen that players' performances depend on their number of play sessions. All things being equal, it is evident that the youngest players belonging in majority to the category of players with a primary, or no diploma at all have the largest number of play sessions.

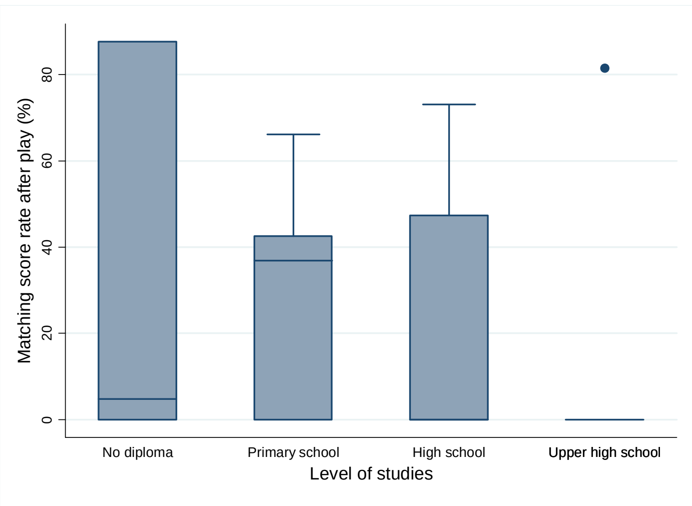


Figure 126: Players' level of studies vs. scores in the Geomalariaquiz after play

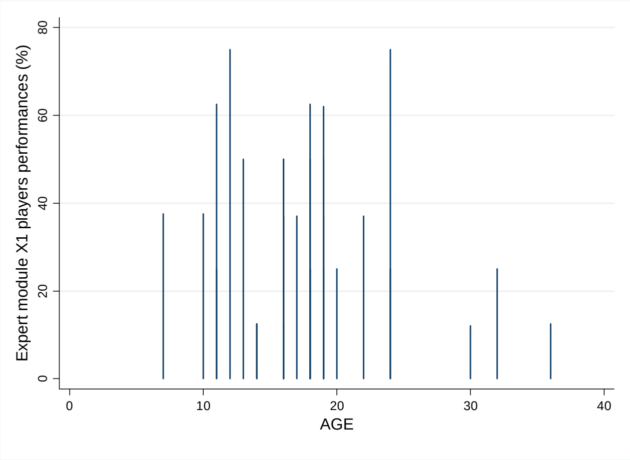


Figure 127: Players’ age vs. performances on the most difficult part of the GeoMalariaquiz

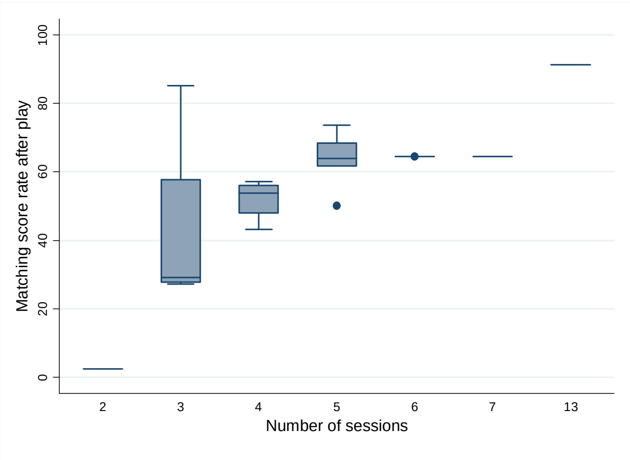


Figure 128: Players’ number of play sessions vs. matching score rate in the Geomalariaquiz after play

6 Discussion and conclusion

6.1 Epidemiological results in harmony with entomological findings

Although malaria studies on Yaoundé from the literature were conducted at different periods, despite the fact that they were concerned with a more reduced spatial support (various zones of the city) they all show close similarities in seasonal variations between *An. gambiae's* daily aggressivity and actual seasonal variation of malaria cases. It can be concluded from these entomological studies (and as it was designed in Chapter 2.5.3.1) that *An. gambiae's,* secondarily *An. funestus,* and *An. moucheti* are the predominant vectors in the peri-urban areas of Yaoundé. The predominant mosquitoes of more densely populated areas are *Culex quinquefaciatus* and secondarily *mansonia* (FONDJO et al., 1992; MANGA et al., 1992; ISABELLA et al., 1996). These last mosquitoes are not really responsible for the malariatransmission to humans. *Plasmodium Falciparum*, the parasite of *An. Gambiae,* is the most dangerous of all the malaria parasites (MOUCHET & CARNEVALE, 1998). *An. gambiae* is not predominant in most of the very "urbanized" areas, but it is not completely absent in central areas. *An. gambiae* was found in a considerable number in a swampy farming valley in the district of Essos (centrally located), sufficient to allow the calculation of an Entomological Inoculation Rate (EIR) (MANGA et al., 1992). It can therefore been hypothesized that these peri-urban species, particularly *An. Gambiae*, are responsible for the local malaria-transmission, at least for clinical cases. This conclusion is consistent with that of Trape and others (TRAPE, 1987; TRAPE & ZOULANI, 1987, TRAPE et al., 1987), who identified *An. gambiae* as being the probable malaria vector in Brazzaville, the capital city of Congo. Brazzaville is ecologically similar to Yaoundé. It therefore implies that peri-urban areas or at least areas with ecological patterns similar to those of peri-urban areas, are more suitable to a local malaria transmission. This hypothesis is consistent with the findings of actual results.

All those studies concluded that the transmission aggressivity of *An. gambiae* follows a similar seasonal scheme to the results of the actual study. The aggressivity is higher during the small and the big rainy seasons for the peri-urban district of Nkolbisson, while this aggressivity was higher only during the small rainy season in the case of the more densely populated district of Melen (Nkol Bikok) (Fig. 125), (FONDJO ET AL., 1992). The results of the study of Essos showed a more similar variation of *An. Gambiae* aggressivity with the malaria prevalence of the actual study. This is consistent with the conclusion of Hammon and colleagues (HAMMON et al., 1956), who stressed that the seasonal variations of *An. funestus* were less important than those of *An. gambiae.*

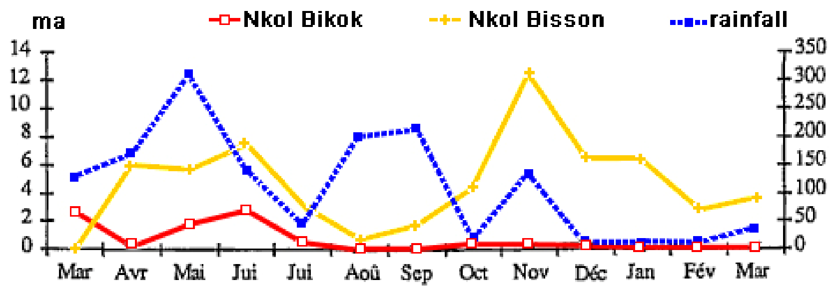


Figure 129: Monthly variation of An. Gambiae in Nkol bisson and Nkol Bikok (After FONDJO et al., 1992)

6.2 Is urban agriculture really a key factor in the malaria-transmission process?

The actual results are also consistent with the assumption that agricultural activities are sustaining the transmission of malaria during the big rainy season in more "urbanized" areas. It implies that the most dangerous vectors are (and can only be) significantly present within agricultural paddies. This is the case in number of studies. Many research projects, conducted in various African cities of the forest and wet savannah zones, and focused on the relationship between urban agriculture (UA) and malaria, concluded that *An. gambiae*, and *An. funestus* are the predominant species in agricultural paddies (BETSI et al., 2003; BRIET et al., 2003; KOUDOU et al., 2005). This conclusion does not account for the presence of *culex*. Some of these studies stressed that there is a higher frequency of breeding sites inhabited by *Anopheles* in the rainy seasons than in the dry seasons (MATTHYS et al., 2006)

In a study conducted in the town of Man in Côte d'Ivoire (a medium-sized town), the authors discovered that irrigation wells which were permanently supplied with ground water represented the most important larval habitats (MATTHYS et al., 2006). This finding is also consistent with the assumption of the transmission sustainability by the effects of UA. Moreover, it implies that during the rainy seasons extensive agricultural activities are facilitated not only by the presence of water within the drains, but also by ground water, which is not the case during the dry seasons. In Yaoundé, the soil in the cultivated inland valleys is hydromorphic with a mixture of fine sand and organic material in decomposition (ENDEMANA et al., 2003). This allows a favourable water-budget during the rainy seasons. The authors also concluded that preferred habitats of *Anopheles* larvae in cultivated areas were rice paddies turbid water, agricultural trenches and irrigation wells (GIMNIG et al., 2001; AFRANE et al., 2004; SATTLER et al., 2005, MATTHYS et al., 2006). Sites with turbid water were significantly more often found in the rainy season than in the dry season (Gimnig et al. 2001, MATTHYS et al., 2006).

In Man, the most highly populated habitats were agricultural trenches (MATTHYS et al., 2006). In Kumassi in Ghana, vegetable farming has been linked to higher anopheline densities (AFRANE et al., 2004). This is in accordance with what is done in Yaoundé. In fact, rice paddies are not found in Yaoundé; "urban peasants" are mainly cultivating lettuces, mainly *Lactuca Sativa*, and local vegetables such as folon (*Amaranthus hybridus),* zom (*solanum nigrum),* tege or keleng keleng *(Corchorus olitorius)* (ENDEMANA et al., 2003; GOCKOWSKI, 2003*)*; ELONG et al., 2008; Commercial UA is practised all year round in Yaoundé (ENDEMANA et al., 2003; ELONG et al., 2008), while domestic agriculture is practised more intensely during the rainy seasons (ELONG et al. 2004). It implies a more active irrigation-process for commercial UA during the dry seasons. Elong and colleagues also noticed that commercial UA was practised in swampy valleys while domestic UA is practised on slopes in Yaoundé (ELONG et al. 2008). Endemana and colleagues revealed that land tenure for agricultural activities was precarious in Yaoundé, 30% are squatting while 36% had either borrowed the land or are renting it (ENDEMANA et al., 2003). This could empirically be related with the intense agricultural activities found within extremely dense PA. It is also consistent with the lowest-elevation values of more rural areas. It is noticed in the case of the towns of Man and Accra that maize plants were widespread in domestic backyards and home gardens (MATTHYS et al., 2006; KLINKENBERG et al., 2008). This observation is consistent with the one made within this study.

Distance to urban agriculture (UA) areas has been identified as a key-factor in the intensity of malaria transmission. A maximal fly distance limit (from the breeding site) of 7 km was observed for *An. Gambiae*. A mean fly dispersion of 1 to 3 km was observed for adult mosquitoes (KAUFMANN & BRIEGEL, 2004). Klinkenberg and colleagues investigated UA related malaria parasite prevalence in central Accra (Ghana). They concluded that the overall malaria parasite is higher in communities around urban agricultural sites (threshold distance of 0 to 1,000 m) than in control communities (a threshold distance superior to 1,000 m). Blood microscopy from children in Accra shows an elevated prevalence of malaria in communities living near UA (KLINKENBERG et al., 2004). Entomologic surveys of the *An. gambiae* yielded higher entomologic EIR in communities close to UA in Accra (KLINKENBERG et al., 2008). Proximity to UA was also positively associated with malaria infection in Ouagadougou, Burkina Faso (WANG et al., 2005). In Kumasi, Ghana, significant more self-reported-malaria episodes are noticed in areas near UA than in areas without UA (AFRANE et al., 2005).

All these studies on UA-distances to potential parasite hosts came to a similar conclusion to the actual study. But, differing in the methodology used within this study to measure the distance of potential hosts to mosquitoes breeding sites, they used a buffering technique. This method is less accurate than the Household Distance to Feature Method (HDFM) used in the current study. As such, the HDFM clearly shows a gradual and more accurate evaluation of exposition to malaria risk according to UA-distances. In addition, it allows calculation of mean values of spatio-morphological PA. The mean distances of all the types of PA are below the threshold distance to UA of 1 kilometre. In the case that the logic of these authors is kept (higher exposition within 1,000 m), it implies that in reality the larger majority of the population is theoretical accessible to *Anopheles* coming from UA. If this logic is not considered, it implies that the sensible threshold distance limit should be revised and reduced, at least in the case of Yaoundé. However, it could be possible that other decisive factors intervene to bias the impact of proximity to UA. Among these factors, small unidentified breeding-sites more probable to intervene in “rural” areas should be considered. This should be made in addition to all unfavourable factors identified in the current study. These factors are notably PA-densities, thresholds and prevention-coefficients. It is assumed that this last element is associated with other socio-economic variables less directly associated with the malaria risk.

6.3 A very low prevalence-rate with a predominant peri-urban risk

It is recognized that the global mortality and morbidity of malaria are altered with the process of urbanization with important consequences on malaria control (HARPHAM & TANNER, 1995; ROBERT et al., 2003). Since the epidemiology, entomology and the sociology of urban malaria are different from those of rural malaria, urban malaria remains a new field of scientific investigations. Among identified interesting subjects in urban malaria studies are the immunology and resistance of exposed population to malaria parasites. The genetical transformation and adaptation of vectors to the urban environment are also important subjects. The complexity and heterogeneity of various urban milieus are additional factors rendering urban malaria a complex issue. The most interesting for medical geography should be the understanding of the spatial production of these probable changes in the urban malaria patterns as well as the provision of tools for a rational intervention. This was the largest part of the contribution of this study.

Keiser and colleagues, in a global study on urban malaria in SSA, found that urban areas are characterized by low malaria transmission. The EIR estimates in urban centers are indicative of a very low malaria transmission. In contrast, higher EIR were found in peri-urban areas (KEISER et al., 2005). Severov and his teammates, in a study conducted in Conakry the capital of the Guinea Republic, concluded that severe malaria cases were mostly found in central less densely populated areas than in peri-urban most populated areas. Fatal *Plasmodium falciparum* cases are frequent in these less densely populated areas (SEVEROV et al., 2000). Similar results are found in Dakar (ANGEL et al., 1994). These results suggest that the level of immunity is of great importance and is one of the main epidemiological factors in urban malaria patterns.

These results are also consistent with those of the current studies. The transmission is predominant in peri-urban districts. The current study also demonstrates that, although being more prevalent in these ecologically more suitable areas, malaria is not associated with pure natural factors such as vegetation or water bodies, but with UA patterns. This contributes to the reduction of the global exposition, because water bodies and mainly vegetation are still predominantly distributed within the administrative boundaries of the city. The current study also demonstrated that the majority of the population is at a low malaria-risk, and that this low malaria-risk is associated with the spatial morphology of the city. The majority of the population belongs to very densely populated aggregates. These populations represent about 68% of the total population (intermediate II, very dense and extremely dense). This demographical pattern does not favour a higher and sustainable malaria-transmission process. A large part of the population of these aggregates was also at a higher distance to UA areas than those of the less dense aggregates. The low malaria prevalence can also be marginally attributed to the general effect of global prevention. In fact, the part of the population enjoying fairly acceptable life conditions (Economic Capacity and crowding coefficient) were at higher preventive protection level against malaria. These populations represent about 31% of the total population (Intermediate II, very dense). It is logically estimated that a part of these populations, from more central areas that have malaria, experienced severe episodes of malaria. Therefore, the mortality is probably higher in these areas with children being the most exposed to fatal malaria episodes. The higher exposure of children is consistent with the results of the study of Kolk and his teammates (KOLK et al., 2003).

What has not been explored within this study is the impact of imported malaria (KAIN et al, 1998). Such an investigation would have demanded a closer meticulous parasitological follow-up of subjects, in order to determine the plausibility of an external transmission. The prevalence-level of subjects who travelled outside of their site could have been used to determine prevalence among them. This would have had no impact on the determination of the favourable local, ecological and social malaria-transmission risks-parameters. However, it remains an interesting subject to develop.

6.4 Urban malaria: A socio-political problem

6.4.1 More environmental variables?

The spatial pattern of malaria associated with the probable major role of UA suggests that favourable ecological conditions for the development of larvae are mainly offered within UA areas. In fact, *An. gambiae* likes stable ecological conditions (HAMMON et al., 1956). It was also remarked that this vector likes newly deforested areas (Manga et al., 1995). *An. funestus* likes grassy swampy conditions (HAMMON et al., 1956). UA areas finally offer a good agreement between the topography and the presence of both water bodies and vegetation. In addition, UA are related to the proximity to human recipients. This is not necessarily the case with vegetation. The turbidity of water drain is biologically more interesting for larvae in UA than in clear or more artificially polluted water bodies (MATTHYS et al., 2006). It can therefore be suggested that vegetation, NDVI, and water bodies do not play an important role in the malaria-transmission process in Yaoundé.

However, additional ecological factors from other sources can be introduced within the model. For a better spatial representation of climate variables, a denser network of ground stations can be created. In fact, climate variables, particularly rainfall, seem to be the most important ecological factors. If introduced within the Mlogit-model, they could considerably achieve the total predictive performances of the ecological model, and therefore the total performances of all the models together. Another important variable that could be used within this model is the Land Surface Temperature (LST). It could be calculated from ASTER-images (JIMENEZ-MUNOZ & SOBRINO, 2007) and used to evaluate the potential blackbody temperatures of various features susceptible to maintain the presence of mosquitoes breeding sites. UA areas could be better and automatically detected by using radar data with the advantage that clouds will not interfere.

A further improvement could be made by spatially extending the entomological surveys and mixing them within a mathematical model together with climate variables. It allows a more dynamic prediction, taking into account the biological variations in time and space of vectors and their cycles. This suggestion follows the line of the School of Liverpool (http://www.lstmliverpool.ac.uk/index.htm). The difference is that the proposed mathematical model would also integrate social and spatial findings of this study.

6.4.2 Social variables need more attention in malaria predictive studies

The contribution of social variables in the transmission of malaria is finally in line with what was found by several authors. The vulnerability to malaria on a social point of view is importantly dependant on the socio-economic status (Economic Capacity). This status is finally a transversal factor to many other important variables, particularly to the level of crowding (ERNST et al., 2006; TAKKEN AND KNOLS, 1999). Some favourable bio-physical factors associated with the level of crowding have been evaluated within this study. The attractiveness, location and identification factors of a potential host by female *Anopheles*, is actually of a growing interest among researchers. At a mean-distance for example (not close to the human host), the carbon gas emitted through breathing is an attractive factor. At a closer distance to the potential host, its relative heat will be particularly important for *An. gambiae* (KELLY, 2001; TAKKEN AND KNOLS, 1999). It means that the higher is the number of people that are sleeping in a room, the higher is the probability they have to be bitten by *An.*

gambiae. The variable room crowding coefficient bears the most important predictive potential within the socio-ecological model.

Also transversal is the economic status with occupational status. The spatial structure of the variable Economic Capacity (EC) is symmetric to that of occupational status. Most people are involved in informal activities (included UA) mainly in extremely dense areas. This socio-spatial stratification finally has an impact on the morphology of malaria, with a considerable number of poor people ecologically protected from malaria in extremely dense aggregates. Poverty leads to the practice of UA in these areas, thus exposing a part of them to the malaria-transmission risks. The economic status of the population is also transversal with the level of malaria knowledge and the prevention capacity. The first factor largely explains the two others.

The socio-ecological factors mainly predicted malaria in households with a high Malaria Relative Risk (MRR). It means that these households experienced several malaria episodes during the same year (2006). It suggests that they permanently offered socio-ecological suitable conditions for the malaria cycles to be completed. The high contribution of socio-ecologic and socio-economic factors to the overall model, as well as the good contribution to the absence of malaria of the preventive factors, suggest that malaria prevalence could be considerably reduced only by changing local socio-ecological and socio-economic conditions. It can therefore be asserted that presence and sustainability of malaria in Yaoundé, as in most of the SSA, is much more a matter of political will. The absence of urban planning, the misappropriation of available funds, and the corruption are and will be the real problems of the burden of urban malaria in those countries. The diagnosis is the same as with many problems in SSA. In the particular case of Yaoundé, this assertion could be related to the fact that the safer areas (very dense and intermediate II) correspond to those where there are municipal- and state-managed proper housing conditions for the population (despite the fact that it is again mostly the richest who occupied these zones). The state of moral decrepitude is such that certain individuals formerly responsible for the “Credit Foncier” and the Ministry of Public Health, together with directors of the malaria-prevention program (some were collaborating with us within this project), are actually in prison. Credit Foncier is a governmental financial institution that is dedicated to deliver funds to both the population and the SIC in order to help in building appropriate housing.

Besides this political digression, the actual model suggests that researchers should give better attention to social factors in general. Proper sociological studies of identified factors and others related to the cultural environment should be interdisciplinary features added in the model with other key factors of an ecological, epidemiological and geographical nature. This could enrich the final model and achieve the predictive capacity of the simulation.

6.5 A tool for decision making

6.5.1 Modelling malaria risks for intervention or research-only purposes?

Compared to the existing malaria models, it can be said that the current approach brought two main innovative points: a higher spatially calibrated predictive modelling and a comprehensive assessment of the intervening factors that are both social and ecological. In addition, all of these points are strategically added together in order to obtain what was called a spatial morphology of malaria. Malaria is a complex disease and urban areas are also complex milieus. It would be pretentious to claim that this complexity has been controlled within this study. However, the basic approach that consists of the integration of multiple factors of various origins is an improving attempt to solve the urban malaria problem.

Despite the importance of climate variables, it is not possible to locally act on global phenomena such as climate for real antimalarial interventions. Therefore, considering social variables remains of crucial importance to optimize malaria interventions, especially in a context of ever-limited resources. The models offer the possibility to target one or many socio-economic or socio-ecological variables for intervention. Making a distinction between socio-economic and socio-ecological items helps in identifying which one can be subject to global macro-economic and political action from local authorities. In this sense, each of the models has its own importance depending on the administrative sector with which it is affiliated.

The model covers the entire city, not parts of the city. Because of the usually limited existing resources to extend spatial surveys of indoor captures of mosquitoes, the results of entomological inquiries on urban malaria are usually not sufficiently spatially extended to detect non peri-urban areas of malaria-risks. Ecological similarities between peri-urban areas and surrounding rural areas ease the work of entomologists who usually prefer to conduct captures of mosquitoes in peri-urban areas. In fact, the large part of the literature dealing with entomology of malaria in Yaoundé reports field inquiries conducted in such peri-urban areas (ADAM, 1956; ANTONIO-NKONDJIO, et al. 2005; BARBAZAN, 1985; FONDJO et al., 1992; KOLK et al., 2003; LANGUILLON, 1937; MANGA et al., 1993). This concentration in peri-urban areas constitutes an evident spatial limitation to malaria control.

The information Z_i (malaria risk) contained in the maps inferred within most of the existing predictive models necessarily bears very high spatially autocorrelated information when focused on higher spatial resolution (U_n) than the entire continent or country (see fig. 130). In addition, when considering real antimalarial intervention purposes, they do not allow an intelligent distribution of the few available resources

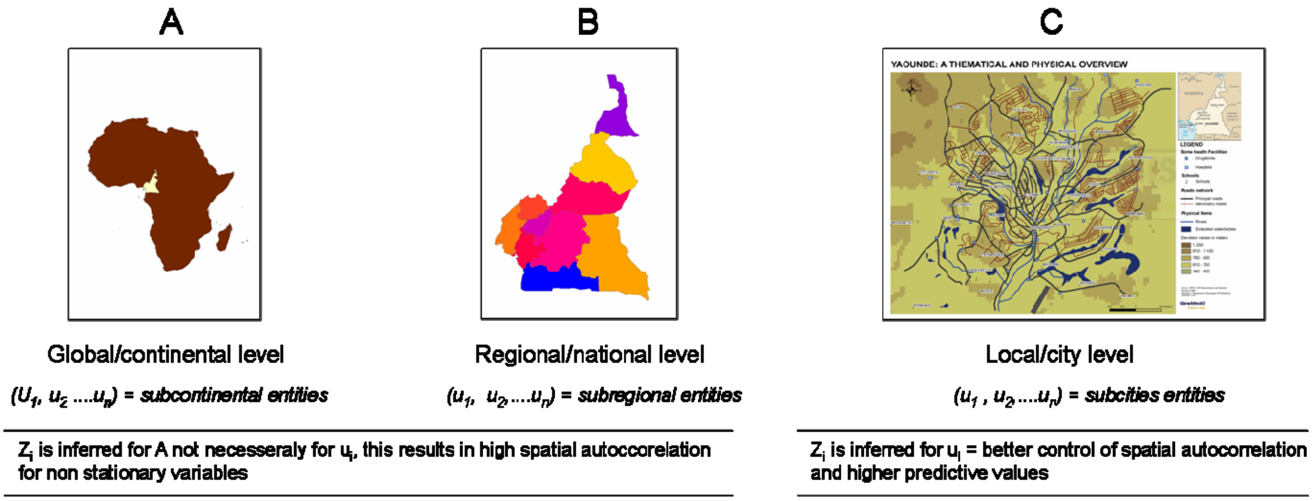


Figure 130: Ecological error induced by broader scale malaria predictive models (After NGOM & SIEGMUND, 2009[a])

Many malaria studies used reported clinical malaria cases from hospitals as a source to model urban malaria risks (SEVEROV et al., 2000, WANG et al., 2005). This data source does not allow the separation between imported malaria and *in situ* malaria. From a spatial point of view, this data source is not accurate enough to be used for modelling purposes. In addition, urban malaria is usually correlated with man-made micro-breeding sites that can only be detected at the household level (KEISER et al. 2004; WANG et al., 2005). Although cautions can be made on the methods based on interviews surveys, the methodological approach developed in this study has the advantage to overcome these spatial shortcomings. The model allows observations and analysis at a very highly calibrated spatial level (dense household's network).

6.5.2 Automating the prediction

The final desirable objective of these modelling-processes is to obtain an automated tool that will help the authorities and NGOs in the prevention and management of urban malaria risks. This tool is supposed to take the form of an automated module with spatial and statistical components. For a better resource optimisation, the inputs of the automated modelling process should be reduced as far as possible. It is at this level that the modelling components based on remotely sense data intervene. The IU, the PA, and the Fuzzy Logic simulation, are key steps towards this automated prediction process. Seasonal variations can be tested using the Fuzzy-modelling approach augmented with seasonal remote sensing imagery (dry and rainy season), in order to take into account the seasonal variability of rural components augmentation, such as vegetation. ASTER-data for the two seasons can then be introduced and vegetation features extracted. The actual knowledge-base can be achieved and updated with .an augmentation of new remotely sensed data. Markov-chain analyses could be additionally used to detect and predict the land use and land cover change. This will allow anticipation in the prediction of major changes of the morphospatial structure of the city.

As a more adequate and complete prospective in managing such a system, Multi Agents Systems (MAS) should be considered. All the richness and flexibility of Artificial Intelligence (IA) can be advantageously used to consider the model in a more global approach. That implies not only considering the automated module, but also all the elements that intervene in the management of the risk (see fig. 131) (NGOM AND SIEGMUND, 2009[b]). The system has two global entities: a high or analysis level that corresponds to the conceptualisation and creation of data. The low level has more hardware components and is at the interface with the potential user of the automated predictive tool (GAO et al., 2004). The system is opened to allow the integration of new factors or to adapt itself to the evolution of actual elements influencing any change into the malaria risk (TANG et al., 2001). The relationships between the elements of the system are defined by a clear ontology that is partly identified within this study. The software applications of these relationships are defined by an adapted IA language.

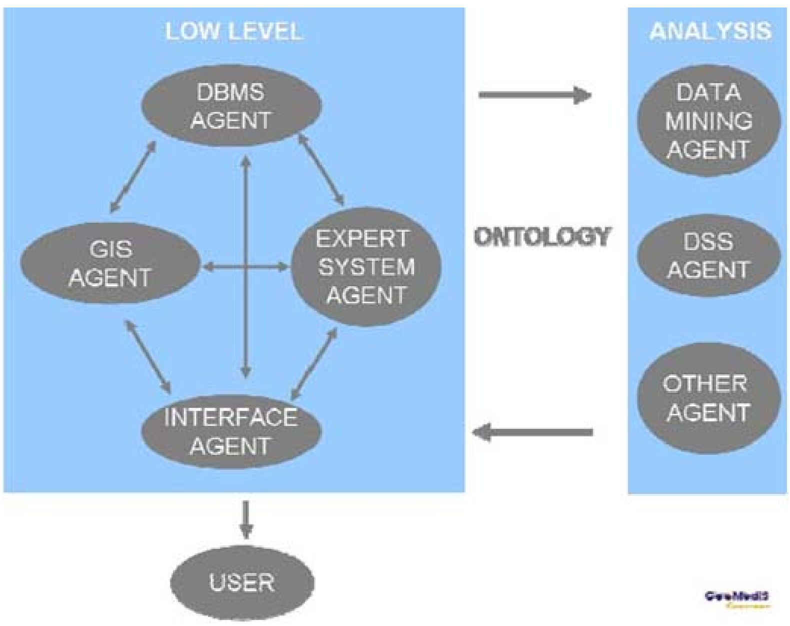


Figure 131: Conceptual diagram of a proposed Multi Agent System (MAS) (After NGOM AND SIEGMUND, 2009[b])

The key element of the high level of this system is the Data Mining System (DMS) (IAN et al., 2005). It corresponds to the data conceptualisation, integration and statistical treatment as it has been done within the actual study. This element hosts all the richness of the basic scientific research on urban malaria. It implies changes and achievements in the concepts and analyses. The Data Surveillance System (DSS) corresponds to the method of field data collection as it was defined within this study. The update of the database depends on the DSS. The methods used within the DSS are also subject to change. In a decentralized management perspective, the analysis level could integrate agents that represent the vision of the political management of the malaria risk. This could correspond to the administrative staff of a district or to the government. The opinion and influence of the civil society is also expressed here. In fact, any political decision concerning the urban management or antimalarial programs can impact positively or negatively on the malaria risk.

The low level of the MAS integrates elements that are tested and validated in the high level. It is fashioned like an Early Warning System (EWS). The most original element is the Expert System (ES) (GAO et al., 2004). It will integrate the algorithms that allow the system to be more intelligent. It could, for example, integrate the Fuzzy-reasoning and the knowledge-base developed within this study. It could, by the way, define rules for suitability or non-suitability. Among many elements, these rules could integrate the dynamism of the relationship between spatially extended climate variables and entomological elements. The Database Management System (DBMS) agent contains data ready for use by the GIS agent (LUO et al., 2000; GAO et al., 2004); it has the normal attributions of a DBMS. It considers variables selected within the final statistical model, which will allow memory saving. It considers the algorithms developed at the level of the ES. The GIS agent contains all the basic elements necessary for the production of maps. It also integrates the algorithms of the ES. It is closely related to the DBMS. The GIS agent is sharing its resources with the Interface agent that could be a dedicated module, programmed for the user who is not an expert in the domain.

6.6 An innovative pedagogical approach for antimalarial campaigns

6.6.1 Scientific information successfully transmitted to the population

There exist malaria fun tools aimed at helping in the prevention of this crucial public health problem. Most of them are made under the form of a quiz on a paper support, as was done for the Malariaquiz. The results of the current study show that any quiz may be too informative and somewhat less interesting and motivating for the players even if some virtual "motivation" objects like virtual money are added. The current study also demonstrated that malaria is not well known. This low level of malaria knowledge is associated with favourable socio-economic conditions for the transmission of malaria. It suggests that a better knowledge could lead to improved malaria prevention.

The question was to know how to transmit information that is of real importance to malaria and at the same time more complete or comprehensive. Promising results are obtained from the proposal to transpose information retrieved from scientific results into tools that are compatible with both the cultural sociology and the strategic availability of media among the target public. In this regard, the approach used within this study is innovative. The information contained within the tools is adapted to the environment in which people live. The multiplication of types of supports allows transferability to various types of population in various social milieus. Despite the presence of complex items within the games, it is evident that the frequency of play achieves the level of malaria knowledge of the population. This is the main goal of these procedures. In fact, the game is made to be played frequently. The interest and motivation expressed by the players in the games is an indicator of the attractiveness of the actual antimalarial games. A next step would be to conduct a follow-up study in order to evaluate the real impact of the level of malaria knowledge on the risk reduction.

Games are completely absent as pedagogical tools in Yaoundé schools as in most of the SSA countries. The concept consists of an investment in the future generations by upgrading their level of malaria knowledge in schools. It is hypothesized that only a comprehensive understanding of the malaria problem can lead to a sustainable solution. The high alphabetisation rate of urban areas is an opportunity to dispatch such tools into schools. Schools can also be used as scientific information sources in a horizontal system (see fig. 132).

This system will be using Google Earth in order to build-up a community with selected pilot schools. This data collection system could be added as an element of the DSS agent. The advantage is the regular collection of epidemiological and social variables, as well as the monitoring of the educational aspect. The focus on Google Earth allows the integration of the risks maps, from both the participative approach of the school children and the actual risk maps. School children will be at the same time gaining an expertise in spatial approaches.

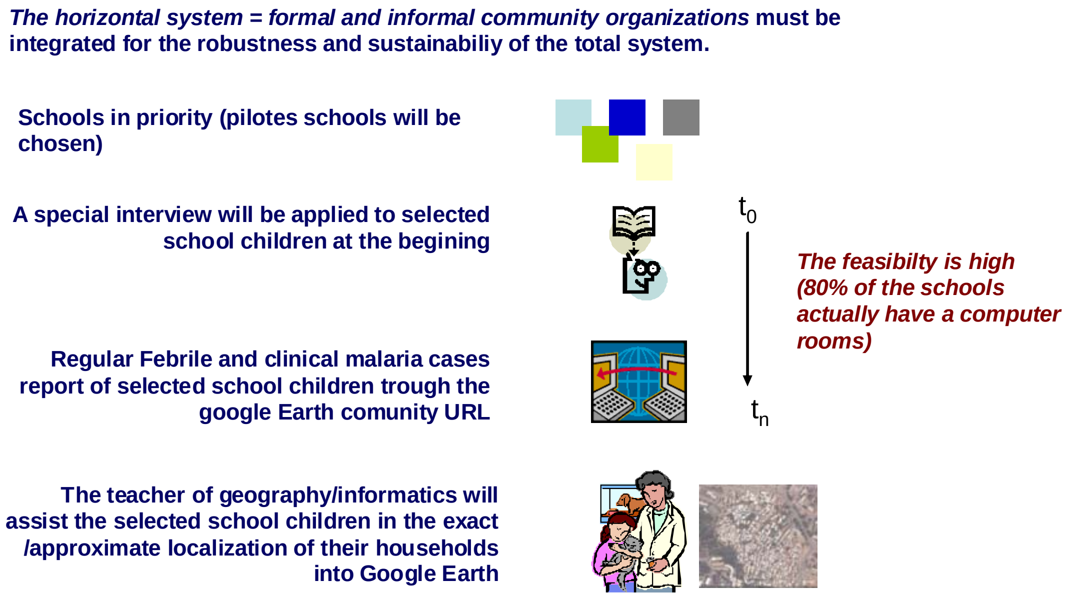


Figure 132: Horizontal prevention system integrating a participative approach in Google Earth (After NGOM & SIEGMUND 2008)

6.7 Conclusion

The starting hypothesis of the study was that a comprehensive approach integrating ecological and social variables in a reduced spatial support would help in a better understanding and modelling of the population vulnerability to malaria, as well as optimising the resources for urban malaria prevention. Another hypothesis was that the introduction of the modelling results in adapted pedagogical tools would offer a good base for a comprehensive and sustainable malaria-based information transfer to the population.

The aggregation of various predictive variables of closer thematic relevance into various sub-models shows that the socio-ecologic factors indicating the crowding at the household level are the most relevant to the vulnerability of the population. These crowding conditions are symmetric to the various socio-economic conditions of the population to malaria. However, a morphological analysis of the spatial distribution of these factors shows that a large part of the poorest, that constitute, by the way, the largest part of the Yaoundé's population, is not significantly exposed to malaria. This safety is attributable to their location in and around the oldest most populated nucleus of the city. They are sharing this demographical and geographical characteristic with the richest population that are established in planned zones, and have better, sometimes uniform crowding conditions. This privileged part of the population also has a better level of malaria knowledge and prevention capacity than the others. These two frameworks characterising the poorest and the richest are probably the key factors explaining the general low prevalence rate of malaria in the city of Yaoundé. The morphospatial segmentation of the city finally shows that a significant and sustainable malaria-transmission process is associated with the presence of demographical thresholds. Demographical thresholds proportionally indicate various levels of urbanity. The areas not too densely and those not too less populated are the most exposed.

The impact of the rural patterns is marked by the presence of agricultural activities. Proximity to Urban Agricultural (UA) areas and rainfall are the most important ecological factors associated with malaria in Yaoundé. These UA activities contribute to maintain a high malaria transmission level among the densest and poorest population aggregates (PA) during the big rainy season. The seasonality of the transmission is compatible with entomological findings, with the highest spike located in the small rainy season and a fall during the two dry seasons. This seasonality suggests that *An. gambiae* is playing a key role in the local transmission process.

A Fuzzy Logic-based simulation of malaria transmission, using a knowledge-base elaborated with the information of both statistical and morphospatial models, allows obtaining an optimised, resources-saving prediction base. This approach gives a better overall prediction result than the multinomial statistical modelling approach. With the Fuzzy-based approach it is possible to use only remote sensing data for an automated prediction of urban malaria transmission. This helps for better decision making.

The general low prevalence rates of all the predictive models are finally in accordance with the morphospatial structure of the city. The actual study excluded imported malaria. It identifies malaria hot spots revealing local transmission processes. The multinomial model shows that malaria is frequent within the same households revealing that the same conditions will produce the same effects. The identification of these conditions, together with the spatial added value, are very useful for resources savings in antimalarial campaigns.

The philosophy that guided the proposed pedagogical tools is optimised for efficient antimalarial campaigns. The results of the analysis of these tools show that the scientific information transfer capacity is dependent on the frequency of play sessions which is finally in accordance with the usage of a game.Age and intellectual capacity are not decisive elements. The proven interest of the players,as well as the adaptability of the physical and cognitive supports of the game, allow a strategic diffusion among various types of populations. For demographical, epidemiological and infrastructural reasons, one of the privileged target population categories is the young people.

The actual models should be submitted to improvements by introducing additional ecological factors, considering a longer study period, and trying additional modelling techniques. A more dynamic model should also be developed by introducing the current results into an elaborated global mathematical model.

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Appendix A: Questionnaires

UNIVERSITE DE YAOUNDE I

FACULTE DES ARTS, LETTRES ET SCIENCES HUMAINES

FACULTY OF ARTS, LETTERS AND SOCIAL SCIENCES

DEPARTEMENT DE GEOGRAPHIE
GEOMEDIS PROJECT

Enquête Académique sur

HABITAT ET PALUDISME EN MILIEU URBAIN

PREAMBULE

Cher Madame, Monsieur,
Ceci n'est qu'un questionnaire entrant dans le cadre d'une étude académique sur le paludisme en ville. L'objectif final de cette étude consiste à trouver les meilleurs moyens pour prévenir et soigner le paludisme.
Nous vous remercions profondément de nous accorder de votre temps et votre espace et nous excusons d'avance pour quelconque contre temps ou désagrément que notre présence puisse causer.

QUESTIONNAIRE – MENAGES

Date de l'enquête…………/……………….../ 200

CQ Code questionnaire ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ Q M

QN Numéro du questionnaire ☐☐☐☐☐

CM Code ménage ☐☐☐☐ CGPS Code GPS ☐☐☐☐☐

QUA Quartier ________

NOS Nom du secteur ________ NUS n° Secteur ☐☐☐

A. ECOLOGIE MENAGE

AEH Environnement Habitat *isolé* ☐ *Très isolé* ☐ *dense* ☐

ATH Type d'habitation *Pièces séparées* ☐ *Bâtiment étages* ☐ *Villa* ☐ *simple* ☐ *Autres* ☐

ASO Statut de l'occupant *propriétaire* ☐ *Locataire* ☐ *Logé(e) par une tierce personne* ☐

ATMT Types de matériaux utilisés pour le toit *Toles en Aluminium* ☐ *Pailles* ☐ *Tuiles* ☐ *Autres* ☐

ATMM Types de matériaux utilisés pour les murs *Béton* ☐ *Briques de terre* ☐ *Planches* ☐ *Terre battue* ☐ *Pisé/poto poto* ☐ *Tôles* ☐ *autres* ☐

AAP Alentours proches ? *Rigole ou ravin* ☐ *Végétation* ☐ *Puits/Source* ☐

ATV type de végétation rencontrée *Touffue* ☐ *dispersée* ☐ *arbres* ☐

APA Présence permanente d'animaux domestiques ? *oui* ☐ *non* ☐

APC Nombre de pièces à coucher ☐☐

ATM Y-a-t-il des grands trous dans les murs ? *oui* ☐ *non* ☐

APP Présence plafond ? *oui* ☐ *non* ☐

AWC W.C *internes* ☐ *externes* ☐

AEO Etat des ouvertures *Portes sans battants* ☐ *Fenêtres sans battants* ☐ *Présence plafond* ☐ *Présence grillages* ☐

B.INFORMATIONS ENQUETE

B1. Informations civiles

B1CE Code enquêté Q M

B1AG Age — B1.SX Sexe *Masculin* *Féminin*

B1DI Date d'installation dans le site *Mois* *Année*

B1PR Provenance *Autre quartier* *Nom* *Village* *Autre ville*

B1SM Situation matrimoniale *Marié* *Célibataire* *Nombre d'enfants en charge*

B1PM Nombre de personnes vivant en permanence dans le ménage

B1CM Etes vous le chef du ménage ? *oui* *non*

B2. Informations économiques et sociales

B2NE Niveau d'études *Primaire* *Secondaire* *Supérieur* *aucun* *Enseignement coranique*

B2AP Activité principale *INF* *CM* *AG* *FC* *LB* *Autres*

B2NR Niveau de revenu mensuel du ménage *1* *2* *3* *4* *5* *6*

B3. Connaissance et Prévention paludisme

B3TP Savez-vous comment se transmet le paludisme ? *Moustique* *eau* *Végétation* *Animaux* *La nuit* *Homme* *Autres* *Aucune idée*

B3MO Dormez-vous sous une moustiquaire? *oui* *non*

B3MI Est-ce une simple ou une imprégnée ? *Simple* *Imprégnée*

B3PM Combien de personnes dorment sous une moustiquaire dans votre ménage ?

B3PMI Combien sont-elles imprégnées ?

B3AP Achetez vous des antipaludéens pour prévenir le paludisme? *oui* *non*

B3APF Si oui à quelle fréquence ? *1/semaine* *1/mois* *1 à 3 fois/an*

B3IE Que faites-vous d'autre pour éviter le paludisme ? *Insecticides* *Nettoyage environnement*

B4. Infection et soins

B4AM Où achetez-vous souvent vos médicaments ? *Pharmacie/Hôpital* *Rue* *Autres*

B4PP Que vous prescrit-on généralement lorsque vous souffrez du palu ?

B4IP Avez-vous souffert du paludisme depuis le 1er janvier 2006 ? *oui* *non*

B4MI Pendant quel(s) mois (Veuillez cocher ici SVP)

2		0			0			6				2		0				0			7		
J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*

B4VY Avez-vous voyagé avant pendant ou après l'un de ce(s) mois là ? *oui* *non* *lesquels*

B4PE Etiez-vous enceinte pendant ces mois-là ? *oui* *non*

B4CM Combien de fois avez-vous eu la confirmation d'un médecin lors de vos crises de paludisme ?

B4SP Sinon pourquoi avez-vous pensé que c'est le paludisme ? *Maux de tête* *Fièvre* *Fatigue* *Nausées* *Mal au foie* *Diahrée* *Autres*

B4TP Qu'avez-vous fait par la suite ? *Automédication* *GIC Santé* *Centre de santé* *Grand Hopital* *Tradi-praticien* *Rien*

B4MMI Combien d'autres membres du ménage ont-ils souffert du paludisme depuis le 1er janvier 2006 ?

B4MIC

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
âge									
sexe (barrer la case inutile)	M F	M F	M F	M F	M F	M F	M F	M F	M F
Mois et année d'infection	/ 200	/ 200	/ 200	/ 200	/ 200	/ 200	/ 200	/ 200	/ 200
Cas cliniques (cocher)									

B4FH En cas de fièvre, maladie ou de paludisme dans quel hôpital / centre de santé allez-vous le plus ?

GeoMedIS Cameroon

SYSTEME D'INFORMATIONS GEOMEDICALES POUR LE CAMEROUN

Enquête Académique sur la

CONNAISSANCE ET PREVENTION DU PALUDISME A YAOUNDE

PREAMBULE

Chers professeurs, éléves ou parents,
Ceci n'est qu'un questionnaire entrant dans le cadre d'une étude académique sur la connaissance et la prevention du paludisme en ville. L'objectif final de cette étude consiste à trouver les meilleurs moyens pour prévenir et soigner le paludisme.
Nous vous remercions profondément de nous accorder de votre temps et votre espace et nous excusons d'avance pour quelconque contre temps ou désagrément que notre présence puisse causer.

QUESTIONNAIRE –ECOLES/LYCEES

Important: ***Les cases rectangulaires qui sont déjà remplie correspondent aux codes question elles sont suivies des questions auxquelles vous devez répondre. Les cases rondes sont à cocher et les cases rectangulaires vides sont à remplir.***

Date de l'enquête…………/…………… …./ 200

A. IDENTIFICATION ET INFORMATIONS SOCIALES

CQ Code questionnaire Q E

ANOM Quel est ton nom? AAGE Quel est ton âge? *Ans*

ASEX Est-tu ? *Un garcon?* *Une fille?*

AQUA Dans quel quartier habites-tu?

ADIQ Depuis quand habites-tu ce quartier? *Mois (remplir les deux chiffres du mois correspondant)* *Année*

APRO Ou habitais-tu avant? *Autre quartier* *Nom?* *Village* *Autre ville*

AEMP Ton papa est: *Fonctionnaire* *Avocat / huissier* *Ne travaille pas* *Autres (préciser)*

AEMM Ta maman est: *Fonctionnaire* *Avocat / huissier* *Ne travaille pas* *Autres (préciser)*

ANEP Ton papa ou ta maman a (Cocher le niveau le plus elevé) *CEPE* *BEPC ou CAP* *Bacc* *Licence ou maitrise* *pas de diplômes*

B. MEDIAS

BORD Avez-vous un ordinateur à la maison? *Oui* *Non*

BORE Apprenez-vous l'informatique avec des vrais ordinateurs dans votre établissement? *Oui* *Non*

BFIN A quelle fréquence vas-tu sur internet? *Tous les jours* *Au moins une fois par semaine* *Très rarement* *Pas du tout*

BFJV A quelle fréquence joues-tu aux jeux videos? *Tous les jours* *Au moins une fois par semaine* *Très rarement* *Pasdu tout*

BOJX Oú joues-tu souvent aux jeux videos? *Au bar* *Sur ordinateur à la maison* *Sur internet* *Sur Nitendo* *Sur Playstation* *Sur mon téléphone potable* *Nulle part*

BJMO Joue-tu souvent au monopoly ? *Oui* *Non*

BJST Sinon à quel jeu de société joues-tu le plus?

BLJN Peux-tu lire un journal, une lettre ou une affiche ? *Oui* *Non*

BFLJ A quelle fréquence lis-tu un journal? *Tous les jours* *Au moins une fois par semaine* *Très rarement* *Pas du tout*

BFER A quelle fréquence écoute tu la radio? *Tous les jours* *Au moins une fois par semaine* *Très rarement* *Pas du tout*

BFRT A quelle fréquence regardes-tu la télé? *Tous les jours* *Au moins une fois par semaine* *Très rarement* *Pas du tout*

BTEM Quel type d'emissions ou d'article tu aimes ? *Informations* *Sport* *Musique* *Films* *Documentaires* *Autres*

BEXS As-tu déjà suivi un exposé concernant la santé? *Oui* *Non*

BTHE De quoi traitait cet exposé? *VIH/SIDA* *Paludisme* *Autre MST* *Choléra* *Autres (préciser)*

C. CONAISSANCE ET PREVENTION DU PALUDISME

I. Connaissances Théoriques

CCNP As-tu déjá entendu parler du paludisme? ◯ *Oui* ◯ *non*

CMCP Si oui par quel moyen? ◯ *Télévision* ◯ *Radio* ◯ *Journal papier* ◯ *Poster/affiche Autres (préciser)*

Pour chacune des phrases suivantes dites si elle est vraie ou fausse (Cochez une seule case)

CQ01 Le paludisme est une maladie qui attrape les gens au Cameroun ◯ *Vrai* ◯ *Faux*

CQ02 Le paludisme tue beaucoup d'enfants au Cameroun ◯ *Vrai* ◯ *Faux*

CQ03 Le SIDA tue les gens plus que le paludisme ◯ *Vrai* ◯ *Faux*

CQ04 Le paludisme est la première maladie qui tue les gens au Cameroun ◯ *Vrai* ◯ *Faux*

CQ05 Le paludisme tue plus les femmes enceintes et les enfants ◯ *Vrai* ◯ *Faux*

CQ06 Il faut que les femmes enceintes prennent des remèdes pour éviter le paludisme ◯ *Vrai* ◯ *Faux*

CQ07 Quand on a la fièvre c'est qu'on a le paludisme ◯ *Vrai* ◯ *Faux*

CQ08 Quand on a mal à la tête et qu'on chauffe c'est qu'on a le paludisme ◯ *Vrai* ◯ *Faux*

CQ09 On peut soiger le paludisme sans aller à l'hôpital ◯ *Vrai* ◯ *Faux*

CQ10 Quand on a le paludisme, on doit d'abord rester à la maison et aller à l'hôpital si ca devient grave ◯ *Vrai* ◯ *Faux*

CQ11 C'est facile de soigner le paludisme avec les remèdes qu'on vend en route ◯ *Vrai* ◯ *Faux*

CQ12 Il y a des choses que l'on peut faire pour éviter le paludisme ◯ *Vrai* ◯ *Faux*

CQ13 Le paludisme se transmet par une piqûre de moustique ◯ *Vrai* ◯ *Faux*

CQ14 N'importe quel moustique peut transmettre le paludisme ◯ *Vrai* ◯ *Faux*

CQ15 Pour éviter le paludisme il faut enlever l'eau autour de la maison ◯ *Vrai* ◯ *Faux*

CQ16 Pour éviter le paludisme, il faut enlever toute la végétation touffue autour de la maison ◯ *Vrai* ◯ *Faux*

CQ17 Les animaux domestiques comme la chèvre autour de la maison favorisent la transmisison du paludisme ◯ *Vrai* ◯ *Faux*

CQ18 Un être humain peut directement transmettre le paludisme à un autre ◯ *Vrai* ◯ *Faux*

CQ19 On peut éviter les piqûres de moustiques en dormant sous une moustiquaire ◯ *Vrai* ◯ *Faux*

CQ20 On peut éviter le paludisme en buvant les remèdes du village ◯ *Vrai* ◯ *Faux*

CQ21 Les moustiques du paludisme piquent seulement la nuit ◯ *Vrai* ◯ *Faux*

CQ21 Si les moustiques n'entrent pas dans la maison ils ne peuvent pas nous piquer ◯ *Vrai* ◯ *Faux*

II. En pratique

CPMO Dors-tu sous une moustiquaire? ◯ *oui* ◯ *non*

CNPM Combien de personnes dorment sous une moustiquaire chez vous ?

CCPP Tes parents ou toi même achetez-vous des comprimés pour prévenir le paludisme? ◯ *oui* ◯ *non*

CFCP Si oui à quelle fréquence ? ◯ *1/semaine* ◯ *1/mois* ◯ *1 à 3 fois/an*

CAMP Que faites-vous d'autre pour éviter le paludisme ? ◯ *Utilisation des insecticides* ◯ *Nettoyage des alentours de la maison*

CTMT La toiture de votre maison est fait de : ◯ *Toles en Aluminium* ◯ *Pailles* ◯ *Tuiles* ◯ *Autres*

CTMM Les murs de votre maison son en: ◯ *Béton* ◯ *Briques de terre* ◯ *Planches* ◯ *Terre battue* ◯ *Pisé/poto poto* ◯ *Tôles* ◯ *autres*

CEAP Autour de votre maison il ya ◯ *Une rigole ou un ravin* ◯ *De la végétation* ◯ *Un puits ou une Source*

ATV Avez-vous un champs autour de la maison? ◯ *Oui* ◯ *Non* CAEP Des animaux domestiques ? ◯ *oui* ◯ *non*

D. INFECTION ET SOINS

DLAM Lorsque quelqu'un est malade chez toi ou achetez vous les médicaments? ◯ *A la pharmacie ou à l'hôpital* ◯ *Rue* ◯ *Autres*

DTMA Quelle est la marque de médicaments que tu prends souvent contre le palu ?

DRIP As-tu eu le paludisme depuis le 1er janvier 2006 ? ◯ *oui* ◯ *non*

DMIP Si oui pendant quel(s) mois?
(Cocher ici SVP)

2		0				0				6		2		0				0				7	
J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

DVMI As-tu voyagé avant pendant ou après l'un de ce(s) mois là ? ◯ *oui* ◯ *non* Lesquels?

DNDP Combien de fois as-tu eu la confirmation du médecin qu c'était le paludisme ?

DMPR Sinon pourquoi as-tu pensé que c'est le paludisme ? A cause: ◯ *des maux de tête* ◯ *de la fièvre* ◯ *De la fatigue* ◯ *Des nausées* ◯ *Du mal de foie* ◯ *De la diahrée* ◯ *Autres symptômes*

DCSP Qu'a-tu fait par la suite ? ◯ *je me suis soigné moi même* ◯ *je suis allé à un GIC Santé* ◯ *je suis allé à un centre de santé* ◯ *Je suis allé dans un gand Hôpital* ◯ *je suis allé chez un tradi-praticien* ◯ *je n'ai rien fait*

DSSR En cas de fièvre, maladie ou de paludisme dans quel hôpital / centre de santé vas-tu le plus ?

E. EVALUATION DES OUTILS D'EDUCATION

EPUP As-tu déja suivi une publicité qui explique comment éviter le paludisme? ◯ *oui* ◯ *non*

EMPP Si oui par quel moyen? ◯ *A la radio* ◯ *A la télévision* ◯ *Sur une affiche ou un poster* ◯ *Dans un journal* ◯ *Sur Internet* *Autres (préciser)*

EFPP Si oui est ce que vous entendez régulièrement des publicités comme ca? ◯ *oui* ◯ *non*

EAPP Est ce que cela t'a aidé à savoir ce qu'il faut faire pour éviter le paludisme? ◯ *oui* ◯ *non*

EOPP Penses-tu qu'on doive faire plus de publicité pour aider les gens à éviter le paludisme? ◯ *oui* ◯ *non*

ETPP Quel genre de publicité peut beaucoup aider les gens à éviter le paludisme? ◯ *Les petits films* ◯ *les grandes affiches* ◯ *Les gens qui parlent à la radio* ◯ *les brochures* ◯ *les jeux videos* ◯ *les jeux de société*
Autres (préciser)

EASM Qu'est ce que vous pensez qu'on peut faire pour aider les gens à éviter de tomber malade?

Adresse électronique de l'élève (facultatif)

Nom et prénoms du professeur (souhaitable)

Adresse électronique du professeur (souhaitable)

Merci beaucoup pour votre disponibilité. Si vous voulez connaitre les résultats de cette enquête, n'hésitez pas à nous les demander.
Contact : ***ngom_roland@yahoo.fr***

Veuillez svp selectionner la date d'aujourdhui

Envoyer par messagerie

CONNAISSANCE ET PREVENTION DU PALUDISME A YAOUNDE

PREAMBULE

Chers joueurs,
Ceci n'est qu'un questionnaire entrant dans le cadre d'une étude académique sur la connaissance et la prevention du paludisme en ville. L'objectif final de cette étude consiste à trouver les meilleurs moyens pour prévenir et soigner le paludisme.
Nous vous remercions profondément de nous accorder de votre temps et votre espace et nous excusons d'avance pour quelconque contre temps ou désagrément que notre présence puisse causer.

QUESTIONNAIRE -POST-EVALUATION-JEUX

Important: ***Les cases rectangulaires qui sont déjà remplie correspondent aux codes question elles sont suivies des questions auxquelles vous devez répondre. Les cases rondes sont à cocher et les cases rectangulaires vides sont à remplir.***

PREQUESTIONNAIRE ◯ **POSTQUESTIONNAIRE** ◯

A. IDENTIFICATION ET INFORMATIONS SOCIALES

CQ Code questionnaire [ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][ ][Q][J][ ][ ][ ][ ][ ]

ANOM Quel est ton nom? [ ] AAGE Quel est ton âge? [ ] *Ans*

ASEX Es-tu ? ◯ *Un garcon?* ◯ *Une fille?*

AQUA Dans quel quartier habites-tu? [ ]

AQUA Quel est ton emploi (travail)? ◯ *Etudiant* ◯ *Elève* ◯ *Fonctionnaire* ◯ *commercant détail* ◯ *sans emploi*

Autres (préciser) [ ]

ANEP Diplôme le plus elevé (Cocher le niveau le plus elevé) ◯ *CEPE* ◯ *BEPC ou CAP* ◯ *Bacc* ◯ *Licence ou maitrise* ◯ *Autres* ◯ *pas de diplômes*

B. JEUX

BJMO Joue-tu souvent au monopoly ? ◯ *Oui* ◯ *Non* BJQZ Joue-tu souvent au quizz ? ◯ *Oui* ◯ *Non*

BJST Sinon à quel jeu de société joues-tu le plus? [ ]

C. CONAISSANCE ET PREVENTION DU PALUDISME

I. Connaissances Junior Senior

CCNP As-tu déjà entendu parler du paludisme? ◯ *Oui* ◯ *Non*

Pour chacune des phrases suivantes dites si elle est vraie ou fausse (Cochez une seule case)

CQ01 Le paludisme est une maladie qui attrape les gens au Cameroun ◯ *Vrai* ◯ *Faux*

CQ02 Le paludisme tue beaucoup d'enfants au Cameroun ◯ *Vrai* ◯ *Faux*

CQ04 Le paludisme est la première maladie qui tue les gens au Cameroun ◯ Vrai ◯ Faux

CQ05 Le paludisme tue plus les femmes enceintes et les enfants ◯ Vrai ◯ Faux

CQ06 Il faut que les femmes enceintes prennent de la chloroquine pour éviter le paludisme ◯ Vrai ◯ Faux

CQ07 Quand on a la fièvre c'est qu'on a le paludisme ◯ Vrai ◯ Faux

CQ08 Quand on a mal à la tête et qu'on chauffe c'est qu'on a le paludisme ◯ Vrai ◯ Faux

CQ09 On peut soiger le paludisme sans aller à l'hôpital ◯ Vrai ◯ Faux

CQ10 Quand on a le paludisme, on doit d'abord rester à la maison et aller à l'hôpital si ca devient grave ◯ Vrai ◯ Faux

CQ11 C'est facile de soigner le paludisme avec les remèdes qu'on vend en route ◯ Vrai ◯ Faux

CQ12 Il y a des choses que l'on peut faire pour éviter le paludisme ◯ Vrai ◯ Faux

CQ13 Le paludisme se transmet par une piqûre de moustique ◯ Vrai ◯ Faux

CQ14 N'importe quel moustique peut transmettre le paludisme ◯ Vrai ◯ Faux

CQ15 Pour éviter le paludisme il faut enlever l'eau autour de la maison ◯ Vrai ◯ Faux

CQ16 Pour éviter le paludisme, il faut enlever toute la végétation touffue autour de la maison ◯ Vrai ◯ Faux

CQ17 Les animaux domestiques comme la chèvre autour de la maison favorisent la transmisison du paludisme ◯ Vrai

CQ18 Un être humain peut directement transmettre le paludisme à un autre ◯ Vrai ◯ Faux

CQ19 On peut éviter les piqûres de moustiques en dormant sous une moustiquaire ◯ Faux

CQ20 Le paludisme tue plus que le SIDA ◯ Vrai ◯ Faux

CQ21 Les moustiques du paludisme piquent seulement la nuit ◯ Vrai ◯ Faux

CQ22 Le moustiquaire peut être utilisé au moins pendant deux ans ◯ Vrai ◯ Faux

II. Connaissances Expert

CQ23 Les insecticides sont le mode de prevention le plus efficace contre le paludisme chez nous ◯ Vrai ◯ Faux

CQ24 Le paludisme peut causer des troubles mentaux chez l'enfant ◯ Vrai ◯ Faux

CQ25 La prevention du paludisme coute plus cher que le traitement ◯ Vrai ◯ Faux

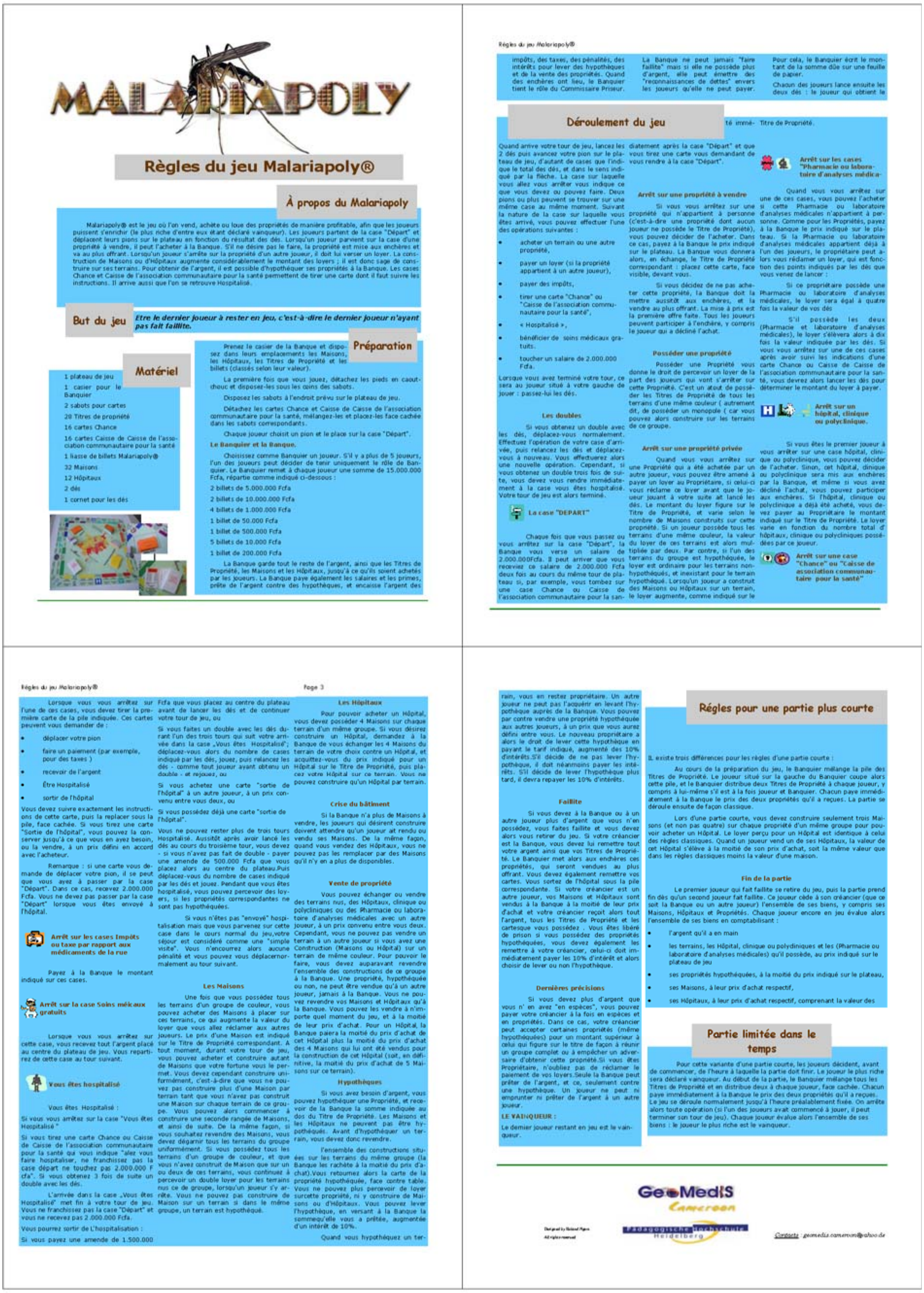
CQ26 La Chloroquine soigne très bien le paludisme ◯ Vrai ◯ Faux

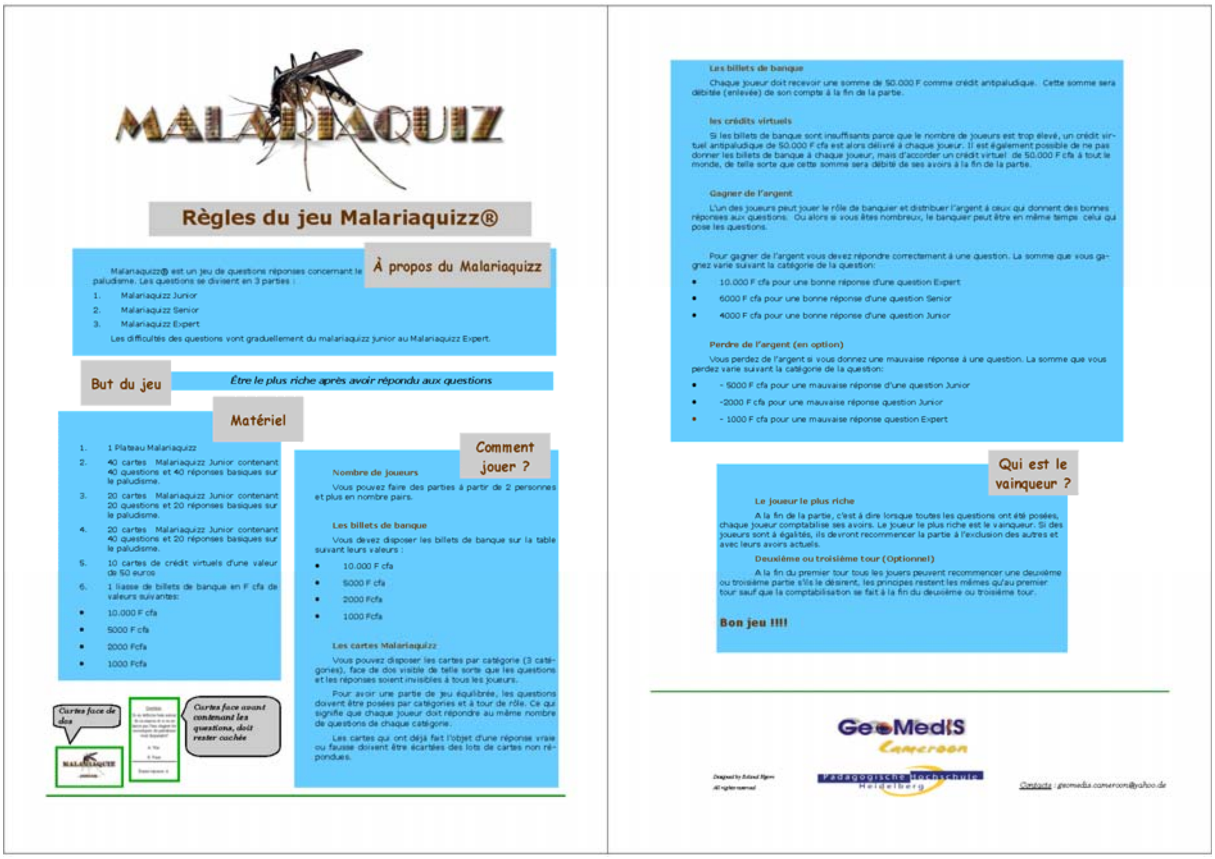
CQ27 On peut savoir tout seul qu'on a le palu sans le diagnostique du médécin ◯ Vrai ◯ Faux

CQ29 Quand on va au village ce n'est pas nécéssaire de se protéger contre le paludisme ◯ Vrai ◯ Faux

CQ30 il est mieux de soigner le paludisme que de le prevenir avec la quinine ◯ Vrai ◯ Faux

Appendix B: Books explaining the rules of the games





MALARIAQUIZ

Règles du jeu Malariaquizz®

À propos du Malariaquizz

Malariaquizz® est un jeu de questions réponses concernant le paludisme. Les questions se divisent en 3 parties :

1. Malariaquizz Junior
2. Malariaquizz Senior
3. Malariaquizz Expert

Les difficultés des questions vont graduellement du malariaquizz junior au Malariaquizz Expert.

But du jeu

Être le plus riche après avoir répondu aux questions

Matériel

1. 1 Plateau Malariaquizz
2. 40 cartes Malariaquizz Junior contenant 40 questions et 40 réponses basiques sur le paludisme.
3. 20 cartes Malariaquizz Junior contenant 20 questions et 20 réponses basiques sur le paludisme.
4. 20 cartes Malariaquizz Junior contenant 40 questions et 20 réponses basiques sur le paludisme.
5. 10 cartes de crédit virtuels d'une valeur de 50 euros
6. 1 liasse de billets de banque en F cfa de valeurs suivantes:

- 10.000 F cfa
- 5000 F cfa
- 2000 Fcfa
- 1000 Fcfa

Comment jouer ?

Nombre de joueurs

Vous pouvez faire des parties à partir de 2 personnes et plus en nombre pairs.

Les billets de banque

Vous devez disposer les billets de banque sur la table suivant leurs valeurs :

- 10.000 F cfa
- 5000 F cfa
- 2000 Fcfa
- 1000 Fcfa

Les cartes Malariaquizz

Vous pouvez disposer les cartes par catégorie (3 catégories), face de dos visible de telle sorte que les questions et les réponses soient invisibles à tous les joueurs.

Pour avoir une partie de jeu équilibrée, les questions doivent être posées par catégories et à tour de rôle. Ce qui signifie que chaque joueur doit répondre au même nombre de questions de chaque catégorie.

Les cartes qui ont déjà fait l'objet d'une réponse vraie ou fausse doivent être écartées des lots de cartes non répondues.

Les billets de banque

Chaque joueur doit recevoir une somme de 50.000 F comme crédit antipaludique. Cette somme sera débitée (enlevée) de son compte à la fin de la partie.

les crédits virtuels

Si les billets de banque sont insuffisants parce que le nombre de joueurs est trop élevé, un crédit virtuel antipaludique de 50.000 F cfa est alors délivré à chaque joueur. Il est également possible de ne pas donner les billets de banque à chaque joueur, mais d'accorder un crédit virtuel de 50.000 F cfa à tout le monde, de telle sorte que cette somme sera débité de ses avoirs à la fin de la partie.

Gagner de l'argent

L'un des joueurs peut jouer le rôle de banquier et distribuer l'argent à ceux qui donnent des bonnes réponses aux questions. Ou alors si vous êtes nombreux, le banquier peut être en même temps celui qui pose les questions.

Pour gagner de l'argent vous devez répondre correctement à une question. La somme que vous gagnez varie suivant la catégorie de la question:

- 10.000 F cfa pour une bonne réponse d'une question Expert
- 6000 F cfa pour une bonne réponse d'une question Senior
- 4000 F cfa pour une bonne réponse d'une question Junior

Perdre de l'argent (en option)

Vous perdez de l'argent si vous donnez une mauvaise réponse à une question. La somme que vous perdez varie suivant la catégorie de la question:

- - 5000 F cfa pour une mauvaise réponse d'une question Junior
- -2000 F cfa pour une mauvaise réponse question Junior
- - 1000 F cfa pour une mauvaise réponse question Expert

Qui est le vainqueur ?

Le joueur le plus riche

A la fin de la partie, c'est à dire lorsque toutes les questions ont été posées, chaque joueur comptabilise ses avoirs. Le joueur le plus riche est le vainqueur. Si des joueurs sont à égalités, ils devront recommencer la partie à l'exclusion des autres et avec leurs avoirs actuels.

Deuxième ou troisième tour (Optionnel)

A la fin du premier tour tous les jouers peuvent recommencer une deuxième ou troisième partie s'ils le désirent, les principes restent les mêmes qu'au premier tour sauf que la comptabilisation se fait à la fin du deuxième ou troisième tour.

Bon jeu !!!!

GeoMedIS Cameroon

Pädagogische Hochschule Heidelberg

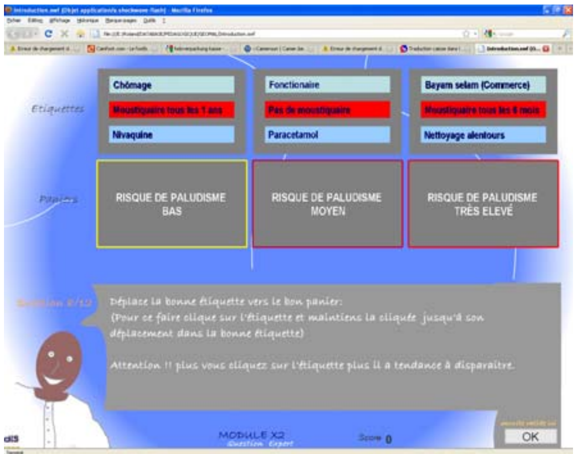
Contacts : geomedis.cameroon@yahoo.de

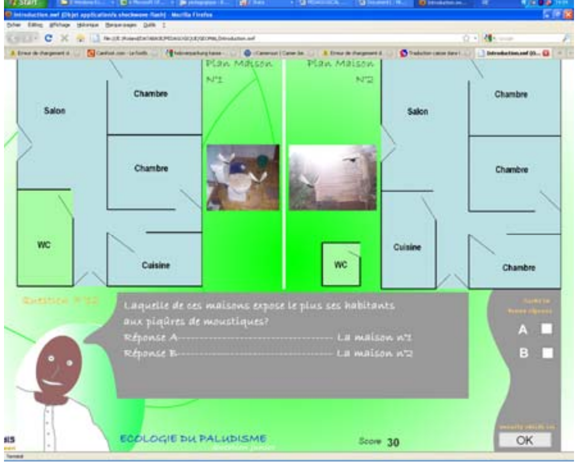
Appendix C: List of questions of the Malariaquiz

JUNIOR-QUESTIONS	SENIOR-QUESTION	EXPERT-QUESTION
Tous les types de moustiques peuvent transmettre le paludisme	Pour pondre ses oeufs Le moutique a besoin	Quels sont les signes cliniques les plus évocateurs d'un accés palustre grave chez l'enfant?
Le paludisme c'est une maladie qui tue plus les enfants	Le vecteur du paludisme s'apelle	Quels sont les 2 terrains dans lesquels le paludisme est le plus susceptible d'entraîner des complications?
Le paludisme tue plus les hommes que les femmes enceintes qui attendent un bébé	Le diagnostique du paludisme est réalisé à partir	Quelles sont les espèces plasmodiales parmi les suivantes?
On attrape le paludisme par la piqure d'un moustique	Parmis les facteurs suivants quels sont ceux qui permettent le développement des moustiques	Quel est le type de paludisme qui peut tuer?
Si on prend des médicaments pour prevenir le paludisme, on ne peut pas l'attraper	Selon l'Organisation mondiale de la Santé, le paludisme tue un enfant	Combien de de pays et territoires dans le monde sont considérés comme zones à risques
Si on defriche bien autour de sa maison et si on ne laisse pas l'eau stagner les moustiques du paludisme vont disparaitre	L'imprégnation d'un moustiquaire avec les insecticides doit etre renouvélée tous les	Parmi les les 4 espèces de parasites suivants qui infectent les etres humains lequel peut causer un paludisme mortel?
s'il n ya pas de moustiques autour de la maison, on ne peut pas attraper le paludisme dans la maaison	Le paludisme tue beaucoup les gens en Afrique parceque	laquelle de ces assertions est incorrecte?
Si la maison a les trous les habitants peuvent attraper le paludisme	Une zone là ou il ya le paludisme tout le temps est appelée	lesquels de ces médicaments ne sont pas recommandés?
Si on dort sous une bonne moustiquaire le moustique du palusdisme ne peut pas nous piquer	tous les médicaments soignent bien le paludisme	Laquelle de ces assertions est incorrecte?
Quand on a été soigné une fois du paludisme on ne peut plus tomber malade de cette maladie	Un moustiquaire traité est plus efficace qu'un moustiquire non traité	le nombre de cas de paludisme recensés dans le monde est de
Le paludisme tue plus les gens en Afrique que partout ailleurs	le moustiquire coute en moyenne	Quels sont les risques de neuropaludisme chez l'enfant?
Les médicaments qu'on vend dans la rue soignent bien le paludisme	C'est plus efficace d'attendre d'etre malade pour acheter les moustiquaires	Le neuropaludisme touche en Afrique les enfants jeunes qui ont une défense immunitaire plus fragile que les adultes; ces enfants sont âgés de
Quand on a le palu ca peut finir tout seul	On peut savoir tout seul qu'on a le paludisme sans le diagnostique du médécin	L'accés palustre est souvent associé á la succesion de 3 phases: Frissons-chaleurs-sueurs
Le moustique qui donne le paludisme pique seulement	les médicaments de la rue peuvent tuer au lieu de soigner	Seules les femelles du moustique piquent et peuvent transmettre le paludisme
Lorsque l'on a le palu on a la fièvre	Parmi les médicaments suivants lesquels sont déconseillés aux femmes enceintes?	le paludisme est une maladie qui touche les gens les plus pauvres
Lorsque l'on a le palu on a la nausée	Parmis les gens suivants quels sont ceux qui peuvent facilement attraper le paludisme?	Dans quelle situation est ce que le cycle du paludisme est susceptible de bien se développer ?
Lorsque l'on a le palu on a la les maux de tête	le paludisme peut se transmettre par	Dans quelle situation est ce que le cycle du paludisme est susceptible de bien se développer ?
Lorsque l'on a le palu on a la diarhrée	Seule la femelle de l'anophèle transmet le paludime	Dans quelle situation est ce que le cycle du paludisme est susceptible de bien se développer ?
Lorsque l'on a le palu on a la le mal de foie	Lorsque les parasites du paludisme penètre dans le sang d'une personne il vont de loger	la prevention du paludisme peut-elle couter moins chère que le traitement?
Lorsque l'on a le palu on a la toux	Parmis les types de maisons suivantes lesquelles permettent aux moustiques de passer plus facilement?	Quel est le mode de prévention le plus efficace contre le paludisme dans les zones endémiques?

JUNIOR-QUESTIONS
Le moustique peut entrer par les fenêtres ouvertes et piquer les habitants
Le moustique du paludisme aime les maisons qui sont en pailles
Lorsque on cultive les champs autour de la maison cela attire les moustiques
L'eau du fossé à coté de la maison ne peut pas garder les moustiques
Si on a des animaux comme les chiens à la maison cela peut favoriser le paludisme
Lorsque l'on a le palu il est bon de rester á la maison et d'attendre que cela passe
Le palu peut empecher de reussir à l'école
Il est mieux de soigner le paludisme que prevenir en pernant les remèdes tout le temps
C'est plus efficace de prendre les remèdes soi même lorsque l'on a le paludisme
Quand on va au village ce n'est pas nécéssaire de se protéger contre la palu
Il ya moins de moustiques dans les endroits oú il pleut que dans les endroits secs
quand on a le palu tout le temps on peut perdre son travail
Le paludisme peut tuer lorsqu'il n'est pas soigné
Le Sida tue plus que le Paludisme en Afrique
Il existe un Vaccin contre le paludisme
quand on est riche on ne peut pas attraper le palu
Le paludisme attaque les gens au village plus qu'en ville
Si je prie très fort les moustiques ne vont pas me piquer
Si je me lave le moustique ne me pique pas
Les filles attrapent le palu plu s que les garcons

Appendix D: Additionnal screens of the Geomalariquiz

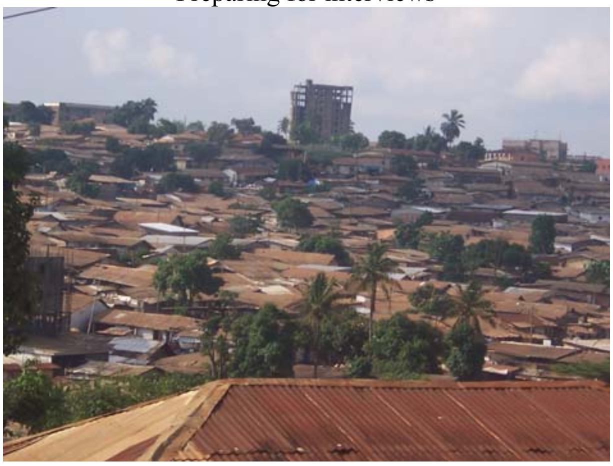




Appendix E: Photographs

Preparing for interviews

Farming activities in Etoudi Yaoundé



Extremey dense area in Yaoundé

Playing the Malariapoly

On the field for interviews

Maize cultivation in a high standing area in yaoundé